JOENSUUN YLIOPISTON YHTEISKUNTATIETEELLISIÄ JULKAISUJA
UNIVERSITY OF JOENSUU PUBLICATIONS IN SOCIAL SCIENCES

N:o 72

Ville Niutanen

INDUSTRIAL ECOSYSTEM CASE STUDIES

The Potential of Material and Energy Flow Roundput in Regional Waste Management

University of Joensuu
Joensuu 2005

Julkaisija Publisher	Joensuun yliopisto University of Joensuu
Toimittaja Editor	VTT Mikko A. Salo
Vaihto	Joensuun yliopiston kirjasto/Vaihdot PL 107, 80101 JOENSUU puh. 013-251 2677 fax. 013-251 2691 Email: vaihdot@joensuu.fi
Exhange	Joensuu University Library/Exhanges P.O. Box 107, FIN-80101 JOENSUU fax. +358 13 251 2691 Email: vaihdot@joensuu.fi
Myynti	Joensuun yliopiston kirjasto/Julkaisujen myynti PL 107, 80101 JOENSUU puh. 013-251 2652, 013-251 2677 fax. 013-251 2691 Email: joepub@joensuu.fi
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ISSN	0781-0350
ISBN	952-458-629-0

Kannen suunnittelu: Esko Puranen
Kansikuva: Jaakko Hosia, *Tripolaris* (1998; akryyli, 217 mm x 178 mm)
Kannen tekninen toteutus: Joensuun yliopiston kuvakeskus
Paino: Joensuun yliopistopaino
Joensuu 2005

Preface

This thesis has been a major attempt for me. All started in the late autumn 1999 when I was first introduced in Industrial Ecology at the University of Jyväskylä. During that time I was planning of my Master's thesis and had no idea of the forthcoming thesis. However, here we are now. The scientific journey of mine has reached its target; the thesis is in satisfactory level for printing. It took great deal of time and patience to finish this thesis alongside with my "day-jobs", and never been accomplished with enormous help of several colleagues and friends whose input has been greatly appreciated.

Professor Dr. Jouni Korhonen has been my supervisor and his experience on and insight in Industrial Ecology and Cleaner Production has been very valuable for this work. Jouni has helped me in so many ways and his ability to write and bring in theories and conceptual approaches from industrial ecology, cleaner production, environmental policy and ecological economics is unique. Jouni's positions as Editor for international scientific journals, as Chair for the International Sustainable Development Research Conference and as the Chair of the Finnish Industrial Ecology Forum have opened up avenues for a Ph.D student to learn from international colleagues and expose the Finnish experience to international debate and critique. These networks and contacts have greatly contributed to my studies and to my learning in the fields of industrial ecology and cleaner production by helping me to follow the international progress that has been made. I greatly appreciate the co-operation with Professor Korhonen and look forward to continuing this in the future.

I am greatly thankful for external reviewers of the thesis, Professor Ilkka Savolainen and Dr. Fredrik von Malmborg for giving me "hard times" during the draft versions of my thesis. Your detailed suggestions and critique for revisions were an important lesson for me. This learning process has developed this dissertation further.

University of Joensuu, Department of Social science has offered me the basis of this work. For doing this work mainly from Huittinen and Lahti more or less as a correspondence, I would like to thank university for its flexibility and help in finishing this work.

There are also highly appreciated persons, whose work have inspired me and given me self confidence for finishing the thesis. Professor Donald Huisingh and Professor Richard Welford gave me valuable comments and encouragement during the thesis. Also the help of Dr. J-P Snäkin, when struggling with the similar thesis of his and many conversations of Industrial Ecology has helped me a lot. Dr. Esa Salminen and Dr. Juhani Suvilampi have been my work mates and I have had a chance to follow up their struggling very close during their dissertations.

The companies where I have worked during the thesis preparation have also been very important for me. I had a privilege to start my scientific career with my master thesis and my first journal article when I was working with Finncao Ltd. Mr. Jaakko Soikkeli from Finncao offered me a change to start everything up. Also Satafood Development Association, especially Mrs. Eila Törmä, encouraged me to continue with food industry waste management projects in Huittinen during 2000 - 2002. Furthermore, Dr. Pentti Lahtinen has offered to me a great position as a project manager in Ramboll Finland Ltd where I have had a change to put Industrial Ecology thinking in practise. I hope this path will accomplish some major development steps in future. I really own my greatest and deepest gratitude for believing in me.

The financial support by the Finnish Cultural Foundation and Emil Aaltonen Foundation is highly appreciated.

Finally, on the personal front, the family has been the most valuable ground for me. My wife Sanna has been extremely patient and she has given me plenty of support during the thesis preparation. Our daughter Nea and our son Niklas have gave me extra strength and sunshine during this work. Also my mom and dad and friends have always being there for me when needed. Without you this would not mean as much as it means to me now, thank you…

Lahti, January 2005.

Ville Niutanen

Tiivistelmä

Tässä tutkielmassa tarkastellaan kahden käsitteellisen materiaali- ja energiavirtamallin eroja. Nykyistä tai vallitsevaa läpivirtamallia sekä potentiaalista tulevaisuuden kiertokulkumallia tutkittiin kestävän kehityksen perspektiivistä. Kyseiset materiaali- ja energiavirtamallit edustavat keskeistä tutkimuksen osaa teollisen ekologian tutkimuskentässä. Kolmea erilaista jätehuoltosysteemiä tutkittiin vastaamaan tutkimuskysymykseen; mikä on teollisen ekologian kiertokulkumallin potentiaali jätehuoltosysteemeissä? Skenaariomallit rakennettiin kuvaamaan erilaisia vaihtoehtoja tietyissä jätehuoltosysteemeissä: 1) maatalouden jätehuollossa, jossa anaerobitekniikka osoittautui teollisen ekosysteemin kiertokulkumallia kuvaavaksi tekniikaksi, 2) Satakunnan jätehuoltojärjestelmässä paikallinen hajautettu jätteiden käsittely käyttäen anaerobitekniikkaa osoittautui teollisen ekosysteemin kiertokulkumallia kuvaaviksi toiminnoiksi ja 3) kaatopaikkojen sulkemisprosessissa pintarakenteena teollisuuden sivutuotteiden ja jätevirtojen käyttäminen osoittautui teollisen ekosysteemin kierokulkumallia kuvaavaksi menetelmäksi. Fyysisten materiaali- ja energiavirtamallien kuvaaminen voivat tuottaa tärkeän ohjaavan elementin teollisen ekologian ja kestävän kehityksen mukaiseen visioon. Kuitenkin, käyttämällä teollisen ekosysteemin materiaali- ja energiavirtamallia ei voida näyttää todellista käytännön polkua kohti kestävää kehitystä. Tästä syystä kestävän kehityksen mukaisen vision käytäntöön panemiseen tarvitaan muita menetelmiä kuin teollisen ekosysteemin metaforaa.

Avainsanat: teollinen ekologia, teollinen ekosysteemi, läpivirtamalli, kiertokulkumalli, materiaali- ja energiavirrat, skenaariot

Abstract

The thesis provides a presentation of the two conceptual models of industrial system material and energy flows in terms of sustainability; the dominant and the unsustainable throughput flow model and the potential future sustainable roundput model. These two material and energy flow concepts serve to illustrate the main research agenda of the emerging research and practical field of industrial ecology. Three different waste management systems were studied to answer the research question: what is the potential of the roundput model in waste management systems? 'What if?' scenarios and models were constructed for different options in three cases: I) for the agricultural waste management, in which the roundput type of technology, anaerobic digestion was defined II) for the Satakunta regional waste management, in which local decentralised treatment of waste flows by using anaerobic digestion for biowastes and incineration for energy wastes were defined as roundput - and III) for the management of old landfill cover layer, in which the waste and side product flows was defined as roundput. In the physical flows of matter and energy the description of the ecosystem flows can produce an important prescription for the industrial ecosystem goal and vision of sustainability. However, the ecosystem metaphor cannot show us any practical solutions to achieve the target of sustainability. Therefore, that for practical implementation of the sustainability vision, one has to use other sources than the natural ecosystem metaphor

Key words: industrial ecology, industrial ecosystem, throughput, roundput, material and energy flows, "what if" scenarios

LIST OF ORIGINAL PUBLICATIONS

This thesis is a summary and discussion of the following articles. Articles appear in international scientific journals with referee practice.

I. Niutanen, V. & Korhonen, J. 2003. Industrial ecology flows of agriculture and food industry in Finland: utilizing by-products and wastes. *International Journal of Sustainable Development and World Ecology*. Vol 10, pp. 133-147.

II. Niutanen, V. & Korhonen, J. 2003. Toward a Regional Management System – Waste Management Scenarios in the Satakunta Region, Finland. *International Journal of Environmental Technology and Management.* Vol. 3, No. 2, pp. 131-156.

III. Niutanen, V. & Korhonen, J. 2002. Management of old landfills by utilizing forest and energy industry waste flows. *Journal of Environmental Management.* Vol. 65, pp. 39-47.

IV. Korhonen, J. & Niutanen, V. 2004. What is the potential of the ecosystem metaphor in agricultural and food industry systems? *The International Journal of Agricultural Resources, Governance and Ecology*. Vol. 3. Nos. 1/2, pp. 33-57.

Niutanen is the first author in three papers included in the thesis (papers I – III). In papers I, II and III Niutanen was the main researcher in all phases of the work, i.e. in the formulation of the research schemes and objectives of the studies, in the calculation of input data, in the development of methods and models and in the presentation of the results. Korhonen played an essential role in theory building in all papers and gave valuable input in structuring and writing processes of the papers. In paper IV, Korhonen is the first author, with building the theory and the methods. Niutanen`s role in paper IV was constructing the modelling and calculations of the study and he served as an assistant in the writing process of the paper.

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1 INTRODUCTION AND THEORY

1.1 Background

The theory in the concept of industrial ecosystem addresses the physical flows of material and energy in a certain region. As a scientific field, industrial ecology is the study of the technologies and flows of material and energy in the industrial, service and use/consumption sectors and the effect of these material and energy flows on the environment. The material and energy flows of the system are studied between the natural ecosystem and the human economic system. IE compares the flows between these two interdependent systems. In provocative and metaphoric terms, authors have suggested that industrial systems should actually "learn" from natural ecosystems (Frosch & Gallopoulos 1989; Tibbs 1992; Ayres & Ayres 1996; Korhonen 2000). The analogy of industrial ecology and industrial ecosystems, which have resulted in increasing popularity of the concept, is still in its initial levels. The natural analogy (i.e. natural ecosystems) is beneficial to map out some future direction in sustainable development, environmental management as well as in regional waste management studies (Korhonen 2000).

The aim of the current and especially future waste management is to systematically promote prevention, safe recovery and final disposal of different waste fractions. In the United Nations Conference on Environment and Development (UNCED 1992) and its document Agenda 21, the concept of sustainable development (WCED 1987) is set to be the priority of the present and future waste management. Sustainable development stresses, therefore, to reduce waste generation, increase reuse of materials and recycling of nutrients in waste, promote energy recovery of wastes and in general to develop environmentally, economically and socially sound waste management. This means a move from the dominating trend of dumping the wastes into landfills towards recycling and reuse of the wastes. Also some recent EC documents stresses above mentioned development (see. e.g. COM 2003).

Furthermore, the importance of holistic, IE orientated thinking or approach to waste management and its functions is becoming more visible in the future. In Finland, the majority of the present and functioning landfills are closed within 5-10 years. Now there are approximately 250 – 300 municipal or industrial landfills in Finland and it is estimated that the number will be reduced to 50-80 by the year 2005 (Ministry of Environment

1998, Tanskanen 2000). The reduction of landfills means demand for new regional waste minimisation and waste management strategies. Because of increasing transport distances of wastes and new environmental requirements for waste treatment, the costs of waste treatment are rising. Furthermore, forthcoming regulations highlight the need to reduce the organic matter in landfilling and that the hygiene aspects of waste management should improve[1]. Therefore, new and more efficient regional as well as local waste management techniques are required.

1.2 Industrial ecology, the throughput and roundput of material and energy

In Industrial Ecology literature and studies, the ecosystem evolution over time has been described with metaphorical models of Type I, Type II and Type III ecology (Jelinski et. al. 1992; Allenby & Cooper 1994; Graedel 1994; Graedel & Allenby 1995 Korhonen & Snäkin 2003). Type I, II and III ecology are presented in figure 1. As noted above, the well-known argument is that industrial systems should actually learn from mature and developed type III, because modern industrial systems are immature in recycling and sustainability.

In Type I ecology, a situation in which there were few species on earth and the resources were abundant is presented (see figure 1 a). There were little interdependency and co-operation or diversity in ecosystems and material flows were linear. This 'throughput' situation can be hypothetically compared to industrial throughput system, where the volume of material is flowing from the environment (input material flows) through the economy and back to the environment as wastes (output waste flows). In throughput energy flow systems, energy is used inefficiently and industrial energy production is based on non-renewable fossil fuels.

[1] Council of State decision (861/1997) stresses that in the year 2005 biodegradable waste fractions are not allowed to be landfilled. Furthermore, the waste act 1072/1993 and the amendment in 1998 (Council of State decision in principle) stresses that in the year 2005 70 % of waste generated should be reused, recycled or utilised as energy. Furthermore, European Commissions (2001) document calls for stringent hygiene aspects in future biowaste management.

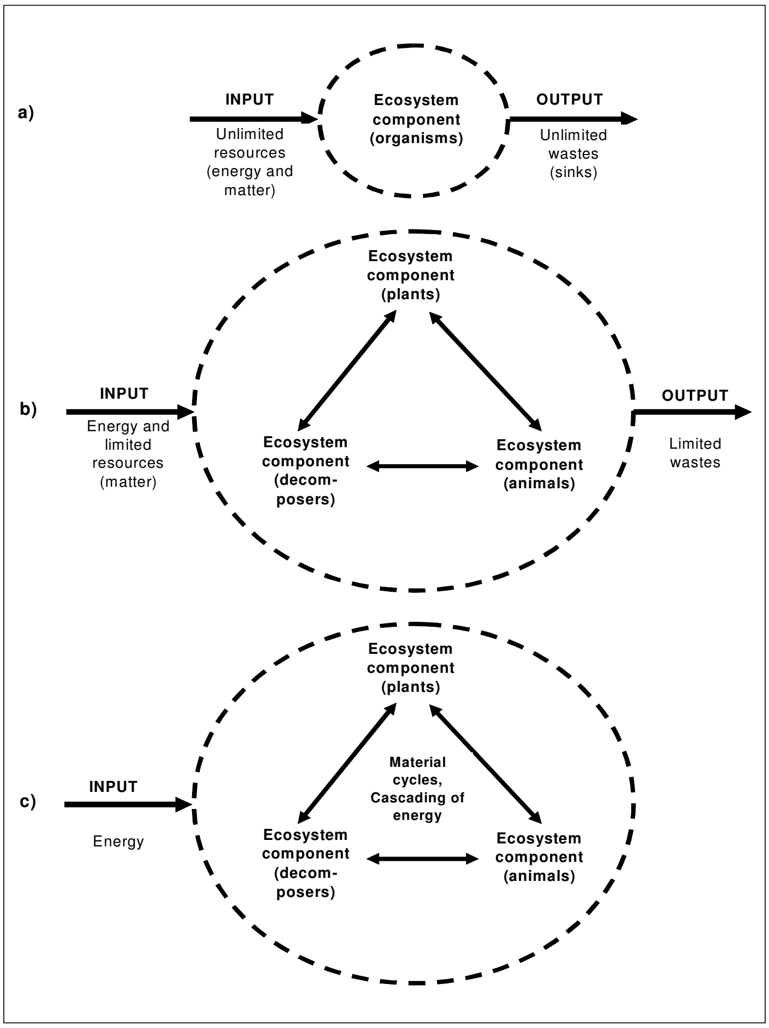

Figure 1. a) Type I ecology with linear materials flows. b) Type II ecology with semi-cyclic materials flows. c) Type III ecology with cyclic materials flows. (Graedel 1994, Graedel & Allenby 1995, Korhonen & Snäkin 2003).

In semi-cyclic Type II ecology (see figure 1 b), the amount of life and species increases. In this new situation organisms and species begin to develop material cycles, energy cascades, and the diversity of the system increases. In Type II, resources are not that abundant relative to the amount of life as before. Perhaps, one could say that modern human industrial and economic systems are still in a linear unsustainable situation between Type I and Type II. For instance, a large portion of the wastes ends up in landfills or directly to nature. Throughout the industrial revolution or development, the flows of matter and energy have mainly been a one-way throughput. Minerals, fibers and fuels are extracted, refined and manufactured into products. Products are dispersed, used, discarded and become municipal or industrial solid waste. In addition, a flow through industrial system emits pollutants and waste into the air, water and soil. However, in recent decades reuse, remanufacturing and recycling systems have evolved, and therefore, to put it provocatively, mimicking the change from "type I" to "type II" industrial society. The process of change from type I to type II is explained by the fact, that industrial actors have largely been in the position of responding to legislation imposed because of a real or perceived environmental crisis. Such a mode of operation is essentially unplanned and imposes significant economic costs as a result. Industrial ecology, in its implementation, is intended to accomplish the evolution of manufacturing from type I to type II and, ultimately, to type III, by understanding the interplay of processes and flows and by optimising the ensemble of considerations that are involved (Graedel & Allenby 1995)

The vision of sustainable economic systems in the future, i.e. "roundput" systems would follow a metaphor in Type III ecology. Here resources are limited, because the amount of life has increased. In Type III there exist nearly completely cyclic flows of matter, energy cascades, high levels of diversity and interdependency in the system. In the ecosystem, for example, trees and other green plants bind incoming solar radiation energy into biomass in the process of photosynthesis. Other organisms utilise this energy in complex food webs. In the food webs, biomass transfers the chemically bound energy in a cascade chain to various trophy levels for the use of organisms. Finally, energy ends up as heat in the physical surroundings and it is radiated back to space (Korhonen 2000). Furthermore, four different and interrelated general goals for industrial ecology with regard to the production and consumption of energy in industrial and in societal consumption systems can be presented. First, industrial systems should use solar energy directly or indirectly through using renewable sources such as hydropower, wind power or biomass, e.g. renewable natural sources such as wood embedded energy instead of non-renewable fossil fuels. Second, the non-renewable stock use for energy in industry and society should be substituted in addition by using industrial and societal wastes as fuels. Third, energy should be used in a cascade-like connection, which would contribute to the effort to reduce the non-renewable stock resources of coal and oil. This means that energy should be utilised in many different quality levels to minimise the losses and increase of entropy (for discussion see Sirkin and ten Houten 1994, Lowenthal and Kastenberg 1998). The lower pressure levels and temperature levels of thermal energy should be used instead of dumping the waste (residual) energy into the ecosystem. Furthermore, the exergy (see Ayres et. al. 2002 and Lowenthal and Kastenberg 1998), which is a concept that defines energy quality as an amount of mechanical work that can be derived from a certain energy source, should be discussed. Exergy is the useful part of the energy. Therefore, in theory, the cascade-type use of energy would minimise the reduction of exergy as the amount of energy that is embedded in a resource and that can be used in industrial activity is increased and in addition, the utilisation time or the economy of the resource is increased (Korhonen 2000). Fourth, the amount of emissions from industrial energy production and use and from end-consumption should be reduced via renewable energy source usage.

Furthermore, type III ecology also calls for energy efficiency between the actors involved, for example, in material recycling. This cyclical system, in terms of the physical flows of matter and energy (cascades), can be defined as "a roundput" system instead of the Type I linear throughput system. In this highly idealised situation the only input to the global ecosystem as a whole is the infinite solar energy and the system is materially closed emitting only waste heat to space. Type III ecology is sustainable.

1.3 Throughput material and energy flows in industrial systems

Industrial material and energy throughput flows follow mostly the linear flow model[2]. The economic system material flow model can be described as throughput, because of the linear material extraction of natural resources, continuing through production and consumption, ending up as emissions and wastes that are dumped to landfills and nature. In figure 2, a certain throughput model is presented in the industrial manufacturing chain. This model is not sustainable.

[2] By this claim, we mean present/modern industrial societies. Desrochers 2002, however, presents some historical examples of rather advanced recycling systems in agriculture and other industrial sectors. However, the historical examples date back from 1800 and early 1900 centuries, and therefore, cannot compared directly to present/modern industrialized societies without more detailed analysis.

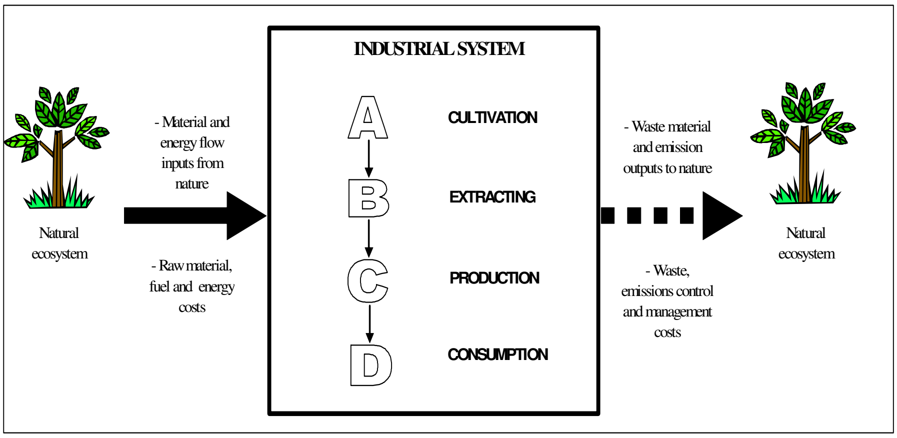

Figure 2. The traditional industrial material and energy flow 'throughput' and the business – environment 'win – lose' situation.

The linear throughput flow model increases the environmental burden of the system and increases material and energy costs as well as waste and emission control and management costs. This system model has been 'a win-lose situation', i.e. the business, the economic system is growing, and the environmental burden of the system has been growing simultaneously (for a win-win see Porter & van der Linde 1996; Walley & Whitehead 1996). Because the natural ecosystem services are becoming increasingly scarce, the societal pressure targets industrial firms, and their environmental performance. Poor environmental practice increases the input and output costs of industry. Now, there lays a risk of a 'lose-lose' situation.

1.4 Roundput material and energy flows in industrial systems

In natural ecosystems, waste equals food and the embedded solar energy is utilised efficiently in the food chain. In the dominant industrial (throughput) systems, the situation is still dramatically different. As described previously, nowadays-industrial systems are operating mostly according to above presented linear throughput model of material and energy flows, or type I or type II ecology. In the linear throughput model, natural virgin materials are extracted, continuing through production and use, and finally the industrial system produces wastes, which are dumped to landfills and emissions, which end up back into the ecosystem. Perhaps the most visible proof of growing human economic systems as still in the linear unsustainable situation of type

I or type II ecology is that, e.g. approximately 80 % of the world energy production relies on emission intensive and unsustainable fossil fuels (Williams 1994). In addition, the resource availability has become more problematic and our wastes and emissions amount in the ecosystem. This is evident for instance in soil/earth construction industry, where suitable natural construction material resources are becoming more scarce (Lahtinen 2001).

Furthermore, traditional agricultural systems were cyclical in nature. In fact, Decrochers 2002 has found some historical evidences of advanced recycling networks in previous centuries in many different sectors of the society. This is despite the fact that much of the industrial ecology literature seems to suggest that loop closing is a 10 to 15 year old innovation (e.g. the Frosch & Gallopoulos 1989 article). For instance; early agricultural societies would grow crops, raise livestock, and spread the livestock manure on fields to enhance crop production. Integration of these processes created a relatively closed, self-sustaining system based on principles of conservation of resources and limited waste. However, the industrialisation or modernisation of agriculture over last century has been the main factor in transforming agriculture from a cyclical process to a linear process with large quantities of raw materials are consumed and large amounts of waste are emitted (Hardy et. al. 2002).

Moreover, there are some examples of rather advanced recycling networks in larger scales in Europe. Paper recycling or bottle recycling systems are relatively efficient for example in Nordic countries. These few examples of modern recycling networks as well as insights into historical evidences, however, serve only a small part of the total industrial related material flows and therefore much larger amount of waste material flows and their recycling are still an open question. In addition, the forthcoming regulations on waste management as well as energy issues related to waste management have not been completely solved.

The principle of roundput[3] is, hence, a step toward an industrial ecosystem, where the matter is recycled and where the energy is cascaded within the different actors in the certain region or between industrial actors. In figure 3, the hypothetical industrial ecosystem roundput vision is presented.

[3] Roundput as a concept was introduced with case studies in (Korhonen et. al. 1999; Korhonen 2000; Korhonen 2001b)

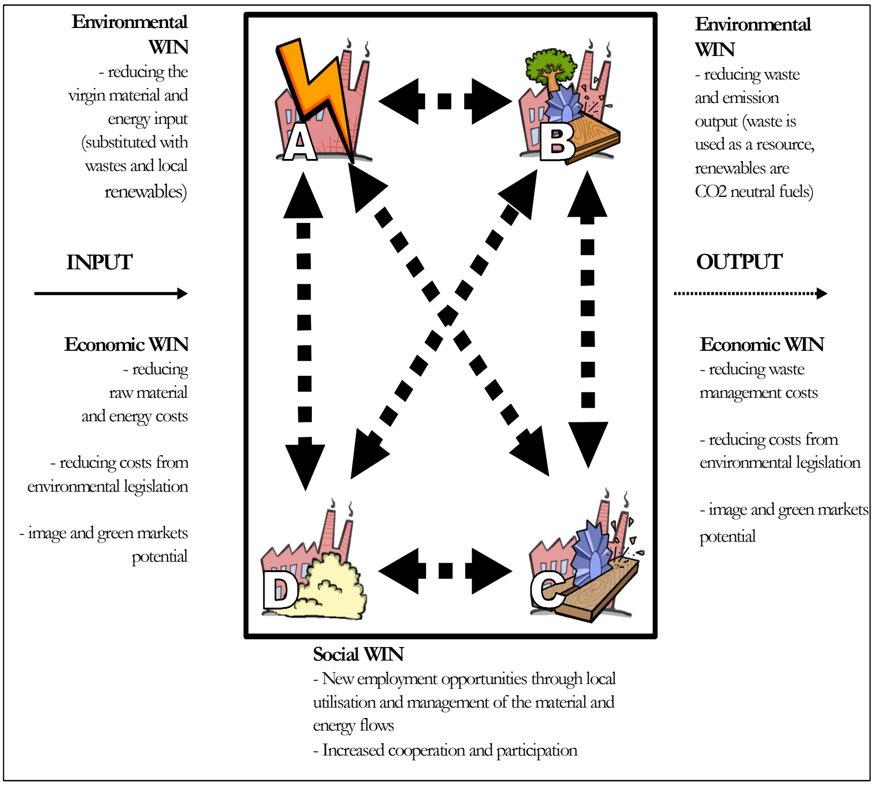

Figure 3. Industrial Ecosystem as a 'roundput' system of matter and energy. Environmental, economic and social 'win – win - win' in the *vision* of a successful local/regional industrial ecosystem

In figure 3, industrial actors (i.e. firms, social actors etc.) A, B, C and D are co-operatively using the waste material flows and cascading energy in the industrial system. In such a hypothetical situation, the virgin materials and energy input as well as the emission and waste output of the system are reduced. At the same time, the system is able to reduce its waste management costs, raw material and energy costs, cost resulting from environmental legislation and by improving system's image benefiting in the (green) markets. In this highly idealised picture, the social win arises through increasing the utilisation of local/regional resources and increasing the self-reliance of the local economy, which can offer employment opportunities for regional inhabitants. Local material and energy flow management can also yield new areas of business and economic activity, e.g. recycling or waste management firms.

2 OBJECTIVES AND SCOPE OF THE THESIS

One of the main visions of Industrial Ecology is to move society towards achieving the co-operative utilisation of waste material and energy. In this vision, the sustainable use of renewable material flows between companies/firms and other social actors in the certain region may lead into an industrial ecosystem where total recycling with zero emissions and waste output is the ultimate target. This, of course, is an extremely difficult challenge, and in fact, will never be achieved 100 %. This thesis cannot answer how this change could be achieved in practise; rather the thesis can only build a vision for practical management and implementation in policy and management, nothing more. Therefore, this thesis must be seen as an attempt to be the “first step” toward practise from highly idealised industrial ecosystem theory.

The objective of the thesis is to give insights into *what is the potential of the industrial ecosystem roudput material and energy flow model in regional waste management systems.*

In other words, the thesis asks what kind of a vision can be presented for waste management systems’ roundput? This thesis does not analyse if roundput is better from a sustainability point of view than throughput. The thesis rather uses the normal assumption of industrial ecology literature that roundput is better than throughput in terms of ecologically sustainable development (Cote & Hall 1995; Cote & Cohen-Rosenthal 1998; Schwartz & Steininger 1997; Tibbs 1992; Jeliski et. al. 1992; Frosch & Gallopoulos 1992; Brand and de Bruijn 1999; Ehrenfelt & Gertler 1997). The thesis focuses on measuring the material and energy flows of throughput and roundput with case studies and supporting calculation models to quantify these flows and their differences. Within this scope, a future estimation on what kind of an alternative there would be for the throughput material and energy flows.

The thesis consists of three case studies, which are performed by modelling material and energy flows by constructing “what if” scenario methodology to evaluate and measure the flows.

In the research articles, first, material and energy flows are evaluated in the case of agricultural waste management in the national, regional and local scale. A calculation model for measuring the differences of throughput and roundput was constructed to quantify the efficiency of different waste management technologies in agriculture (paper I).

Second, material and energy flows are evaluated in the case of Satakunta waste management scenarios. Here the agricultural and food industry manufacturing as well as part of the forestry manufacturing sector waste management throughput and roundput flows are evaluated (paper II and IV).

Third, material and energy flows are evaluated in the case of landfill management procedures of an old landfill closure process. Here the different material flows are evaluated by the terms of energy efficiency as well as material recycling (paper III).

Fourth, research paper IV is a general and conceptual discussion on agrofood Industrial Ecology and the article uses the same data as research paper II.

The thesis concentrates on describing the throughput and roundput technologies in terms of efficiency with material recycling and energy consumption. The thesis also discusses shortly the policy instruments and management concepts of moving from throughput type activities into roundput type activities in regional industrial systems. In addition, some obstacles and barriers of roundput models are discussed.

3 RESEARCH METHODOLOGY

3.1 Introduction

One of the approaches in Industrial Ecology is to measure the opportunities and the links for different actors to steer environmental, economical and social performance in industrial systems, by using different tools and methods (van Berkel et. al. 1997; van Berkel & Lafleur 1997). Life cycle assessment (LCA) is a commonly used instrument for the systems-oriented environmental management. LCA is a technique for assessing the environmental aspects and potential impacts associated with a certain product. LCAs are conducted by compiling an inventory of relevant input and output flows of a product-oriented system from cradle-to-grave (or cradle-to-cradle) and by evaluating the potential environmental impacts associated with those inputs and outputs (ISO 1998, Ross and Evans 2002). In addition to LCA, tools such as life-cycle design (LCD), life-cycle inventory (LCI), design for the environment (DfE), material flow accounting (MFA), substance flow analysis (SFA), material and energy flow models (MFM) material intensity per unit service (MIPS), or eco-balances are used in industrial ecology.

This study evaluates the throughput and roundput material and energy flows, by using "what if" scenarios for material and energy flows in certain regions to contribute to industrial ecology. For measuring the material and energy flows of throughput and roundput, the "what if" scenarios in the cases of agriculture, food and forestry industry and landfill management are constructed. To study the quantity of throughput and roundput flows and to compare these flows by using "what if" scenarios, calculation methodology of input-output models, eco-balance as well as material and substance flow approaches are used.

3.2 Scenario approach: Asking the question "what if or what if not?"

Scenarios are used for comparing different future alternatives. In the first place, scenarios describe processes, representing sequences of events over a period. Scenarios are also hypothetical, describing possible future pathways (van Asselt 2000). Furthermore, scenarios contain elements that are judged respect to importance, desirability and probability (Jungermann 1985).

Decision-making (public and private) is searching compromises, in which the scenario presentation can be a valuable tool (Pesonen 1999, Eriksson 2003, Isoaho & Vinnari 2003). For example, one can calculate four different scenarios for a local industrial material and energy flow system. These, then, can be brought to the decision-making table, where the decision-makers can 'choose' one of the scenarios, their combinations or a compromise between the presented scenarios. This process can then, lead, for instance, investments into IE technology or regional policy/management strategy.

Simplified comparisons of scenarios can be made with the above metaphors or principles of roundput and throughput. Here, one can ask the question: 'Where do we want to go?' These "what if" scenarios are often studies where some specific changes within the present system are tested and their implications to environmental, economical or social comparisons are studied. The results of these studies are quantitative comparisons of the selected options, e.g., how much % of alternative 1 differs from alternative 2. However, when studying material and energy flows in the regional context, where many actors are studied simultaneously, one has to make simplifications and assumptions. In this thesis, the system boundaries as well as the material and the energy flows are presented in the chapter 5 and related appendices I-III.

To construct scenarios, there is a need to know the present situation or the hypothetical situation, to which the scenarios are then compared. In the thesis, inventory tools such as the material and energy input-output and eco-balance analysis as well as the material and substance flow analysis are used to promote this.

3.3 Input-output models, eco-balance and material and substance flow analysis

Material and energy flow studies have been performed with many different approaches, with widely varying scopes. The methodology in material and energy flow calculations is found in the scientific field of industrial ecology (see for instance van Berkel et. al. 1997). However, one dominant feature in all material and energy flow models (whichever the researchers have called it), is the fact of law of conservation of mass (Lavoisier 1789). This principal law of physics indicates, that in a systems perspective, the input flow of mass = the output flow of mass. Input-output analysis and models focus on the linkages of resource use with the changing structure of the environment and economics. This gives a sufficient starting point for evaluating and measurement of regional throughput and roundput material and energy flows in a certain system. Input and output models and analysis are, in addition, an initial study to construct eco-balances, eco-efficiency calculations and material and substance flow analysis.

Eco-balance is a tool especially for the environmental assessment of materials and products (Kurki 1998; White & Wagner 1996). Eco-balance is a mass balance study that involves the listing of environmental input/output data to identify, quantitatively measure and report environmental parameters of the studied system of material and energy flows. Eco-balance is a tool for monitoring and evaluating potential reduction opportunities of raw materials and energy in a certain economic system. Usually eco-balance studies single firm or system. For example, in this thesis the study of input-output analysis of AD processes can be understood as an eco-balance.

Eco-efficiency involves an aim to reduce the environmental load in proportion to the produced economic value. Environmental load may refer to all harmful effects on nature, but its main aspects are the use of material and energy (Mäenpää & Juutinen 2002).

One of the tools most commonly used in material and energy flows studies (i.e. the central studies on industrial ecology) is material flow accounting (MFA). In an MFA the flows of materials in a specific geographic region (country, municipality etc.) are quantified and modelled. A distinction can be made between bulk-MFA and substance flow analysis (SFA). In an SFA the flows of one specific (group of) substance(s) is studied. For example, in this study nitrogen compounds and CO_2 can be observed as an SFA study. In addition, our focus on CH_4 is similar to a SFA. Nevertheless, it must be noted that, this study did not apply any specific method of input-output as presented in the literature of these methods. Instead, the methods used in this study can be presented as kind of a mix of these methods. The principle that connects all articles is that, input-output material and energy flows are studied.

4 CASE STUDIES OF THROUGHPUT AND ROUNDPUT

The concepts of throughput and roundput were introduced in chapter 1, where the theory of the ecosystem evolution over time from type I to type III ecology was described. Chapter 1 presented a metaphor for the theory of industrial ecology literature (Frocsh & Gallapoulos 1989, Tibbs 1992, Jeliski et. al.1992, Graedel & Allenby 1995 and Allenby 1999).

In this thesis, the above presented theoretical metaphors adapted from literature are used as inspiration and source for creative thinking for the future roundput vision in the case studies presented below. This roundput vision for the future is presented as contrasting to the current throughput flow of our unsustainable society. Consider the type I, II and III ecology in the evolution of the ecosystem development over time as described above and in the industrial ecology literature on the metaphor. Note that, the above mentioned literature uses more or less qualitative data of describing the flows of throughput and roundput, i.e. they show how, in what type or in what way materials and energy flow within and between systems. In the thesis, therefore, the ecosystem metaphor is used as the basis and source of inspiration and thinking, but it is not used as an absolute definition of the analysis criteria for the cases. This thesis tries to take a quantitative approach to the case studies for the criteria to analyse practical case studies, and note that these criteria are very different from the metaphor (metaphors are always qualitative). Consider energy efficiency and emission intensity. This means that in our practical case study analysis, roundput means high energy efficiency (in quantitative terms), and low emission intensity (in quantitative terms), while throughput means opposite; low energy efficiency and high emission intensity (again, in quantitative terms).

As described earlier the idea of the roundput was adapted from the industrial ecology literature as a model or a roadmap. However, there are some evidence on the limitations of recycling and roundput in the scientific literature. Recycling of waste reduces the demand for virgin materials, the amount of waste to be landfilled and also reduces emissions from these sources. However, recycling generates waste and emissions of its own (see e.g. Nakamura 1999, Connelly & Koshland 2001). For instance recovery rates of used paper have increased considerably in many European countries during last decades. Landfill capacity is limited which gives pressure that the use of virgin fibre for paper must be reduced. The use of recovered paper may consume less energy than the use of virgin raw materials. However, some reported cases (see Pento 1998a, b; Korhonen & Pento 1999) have shown that high recovery rates of paper may not be the best solution in environmental terms. This means for accumulation of de-inking residues with high concentration of heavy metals (e.g. cadmium). Therefore, the oversimplification that roundput is always a good or the best solution and throughput is a bad is not the “rule of a thumb”.

In the thesis, the attempt of describing the metaphor for a practical model and the thesis tries to take a quantitative level in the case studies for describing the flows of throughput and roundput. These two features are energy efficiency (i.e. energy production or consumption from waste material, when evaluating the treatment methods or the end use of waste) and emission intensity (i.e. CO_2 emissions from waste management options) in the certain waste management systems.

Energy efficiency (in quantitative terms, amounts of fuels used) and emission intensity (in quantitative terms, CO_2 generated) are the main characteristics in the three case studies presented in the next chapter. In case I, the approach on energy efficiency and emission intensity evaluates agricultural waste material treatment of manure (i.e. the alternatives for biodegradable waste management options). Case II adopts the philosophy of case I and adds the flows of food industry and household consumption to biodegradable waste management. In case II also forestry, agricultural, food industry and municipal combustible waste flows are added in the evaluation from perspectives of energy efficiency and emissions intensity. Case III finally adopts a waste flow recycling opportunity from forestry and energy production industries in term of energy efficiency and emissions intensity.

In the following sections and in the appendices I-III, the background and objectives, data sources and the calculation models of “what if” scenario approaches are presented for each of the case studies. In addition, system boundaries, assumptions, limitations and uncertainties of the each study are discussed.

4.1 Case study I: the agricultural waste management system

4.1.1 Objective and scope

This chapter is a review of paper I. In the Finnish agriculture, the main waste fraction is produced manure, approximately 21 million tons annually. About 93 % of the produced manure is recycled in agriculture (Levinen 2001). Therefore, one could make a simplified conclusion that waste manure recycling leans towards a roundput flow and there is nothing left to study especially with throughput versus roundput flows. However, the efficiency in manure treatment especially in terms of environmental and economical aspects has not been studied in a holistical perspective in Finland. Efficiency of manure treatment is dependent on energy balance (i.e. energy production or consumption in manure treatment) as well as fertilising balance of treated manure (i.e. fertilising potential of treated manure with energy balance of avoided need for mineral fertilisers) and furthermore with different emissions factors during the treatment of manure as well as manufacturing process of mineral fertilisers. Furthermore, this waste flow is significant in terms of its magnitude comparing to other biodegradable waste flows (see table 1). Paper I studies these efficiency factors with different manure treatment technologies in the Finnish agriculture as a whole and in regional as well as in municipal systems.

Table 1. Some organic waste fractions and exploit rates (%) in Finland (Levinen 2001)

Waste fraction	Million tons	Exploit rate %
Municipal solid waste	2,4	38
Wastewater treatment sludge*	0,16	91
Food industry waste	1,9	76
Manure	21	93

* dry weigh

4.1.2 Method and used data

The paper I uses national data from Finland, regional data from the Satakunta region in Southwest Finland and local data from the municipality of Huittinen in Satakunta. A methodology, in which environmental, economic and social variables are studied with different "what if" scenarios for the roundput material and energy flow model and for the throughput material and energy flow model is presented.

In model I, the throughput and roundput flows are studied in agricultural waste management, i.e. in manure management. The model is presented in figure 4.

The functional unit of the calculations is defined as an area of one hectare of arable fields **(2)**. In arable fields, between 10 - 40 kg of phosphorus (P) and between 60 – 180 kg/year of nitrogen (N) are allowed to be used as a fertiliser in cultivated one-hectare field. Therefore, hypothetically, the average of 25 tons of manure **(1)** contains the fertiliser content allowed in one hectare (manure contains in average 3.4 kgN/ton and 0.9 kgP/ton).

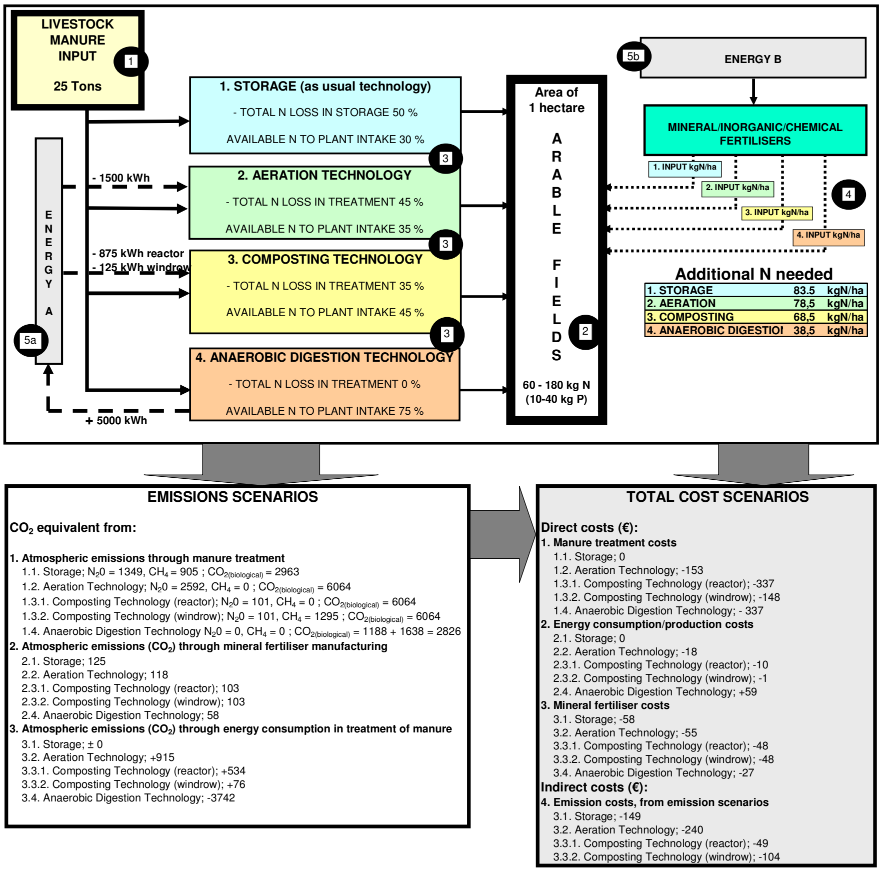

Figure 4. Agricultural manure management scenarios based on different waste treatment techniques/alternatives.

Manure treatment technologies (“what if” scenarios, alternatives) are divided into

- Storage,
- Aeration technology,
- Composting technology and
- Anaerobic digestion technology **(3).**

In general, these treatment methods are causing the loss of nitrogen (N) from manure during the treatments or storage and therefore changing the nitrogen amount available to plant intake of treated manure (when incorporating or spreading the treated material onto arable fields). The loss of nitrogen is defined as total N loss (%) by substances of NH_3 and N_2O or nitrogen gas N_2. Also the availability of total N to plant intake (%) is defined through the total loss of N as well as unavailability to plant intake through biological changes during the different treatments of manure (see appendix

1). Therefore, the input (%) of "extra or surplus" mineral fertilisers **(4)** is needed in arable fields. By using alternative manure treatment technologies, the input of mineral fertilisers varies **(4)**. The variations of mineral fertilisers are compared to storage "treated" manure and the difference (kgN/ha) is given.

In addition, note that the treatment technologies are energy neutral (storage), energy negative (aeration, composting) or energy positive (anaerobic digestion) **(5a)**, and energy for manufacturing of mineral fertilisers **(5b)** is depended on input of fertilisers on arable fields **(4)** **(2)** which is depended on the manure technology used **(3)**.

The data used in the model I is based on secondary data, presented in scientific journals and other publications. Detailed descriptions of the calculation methods, used data, limitations and assumptions are presented in appendix 1.

4.1.3 Results

4.1.3.1 Results of environmental scenario

Table 2 shows the differences in CO_2-balances of different manure treatment technologies from model I. The only technology, which is able to perform a negative CO_2 balance, is the anaerobic digestion technology (AD). This is mainly because of the possibility to produce, instead of consume energy by using the renewable biomass, i.e. manure, as a fuel in anaerobic digestion and substitute the non-renewable fossil fuels with this locally available alternative. The production of energy in AD, with digestion of 15.6 million tons of manure is the amount in national level. 15.6 million tons is the storage capacity of the manure in Finland in the period of one year. Also the Satakunta levels (0,78 million tons of manure) as well as the municipal levels (Municipality of Huittinen, 0,13 million tons of manure) are presented.
For the purposes of the conceptual presentation of this thesis, anaerobic digestion technology seems to be in line with the roundput-type material and energy flow model when presented in terms of our criteria of energy efficiency and emission intensity. It is able to use the energy value in wastes (manure) and it is able to recover the maximum amount of nutrients from the treated manure for using these as valuable nutrients. The other three technologies, storage, aeration and composting are not able to produce energy (aeration and composting are energy negative and storage energy balance is neutral, see figure 5 and table 2) nor are they as efficient in fertiliser recovery as anaerobic digestion. Hence, these three technologies lose fertilising values and energy as in the linear throughput model, while anaerobic digestion is

able to recover the fertilising values and energy more efficiently, i.e. as in the cyclical and cascading roundput model.

Table 2. Emission scenarios from model I. In the table 2, CO_2 emissions from N_2O and CH_4 emissions from manure treatment and through mineral fertiliser manufacturing and energy production/consumption are given with CO_2-equivalents. In addition, biological CO_2 emission during the treatment is given.

TECHNOLOGY IN MANURE TREATMENT AND EMISSION PARAMETER	Reference unit (25 tons) CO_2 eq kg	National level 15,6 Mtons (Finland 2002) CO_2 eq ton	Regional level 0,78 Mtons (Satakunta 2002) CO_2 eq ton	Municipal level 0.13 Mtons (Huittinen 2002) CO_2 eq ton
1. STORAGE				
- N_2O	1 346	840 000	42 000	6 900
- CH_4	905	560 000	28 000	4 600
- CO_2 (biological during treatment)	2 963	1 850 000	93 000	15 000
- mineral fertiliser manufacturing	125	80 000	4 000	600
TOTAL inc. biological CO_2	**5 340**	**3 330 000**	**167 000**	**27 100**
TOTAL CO_2-eq	**2 251**	**1 400 000**	**70 000**	**11 500**
2. AERATION TECHNOLOGY				
- N_2O	2 592	1 600 000	81 000	13 000
- CO_2 (biological during treatment)	6 064	3 800 000	190 000	30 000
- mineral fertiliser manufacturing	118	75 000	6 700	600
- energy consumption (60 kWh/ton)	915	570 000	29 000	4 600
TOTAL inc. biological CO_2	**9 689**	**6 045 000**	**306 700**	**48 200**
TOTAL CO_2-eq	**3 625**	**2 245 000**	**116 700**	**18 200**
3.1. COMPOSTING TECHNOLOGY (reactor)				
- N_2O	101	63 000	3 200	500
- CH_4	0	0	0	0
- CO_2 (biological during treatment))	6 064	3 800 000	190 000	30 000
- mineral fertiliser manufacturing	103	64 000	3 200	500
- energy consumption (35 kWh/ton)	534	333 000	17 000	2 700
TOTAL inc. biological CO_2	**6 802**	**4 260 000**	**213 400**	**33 700**
TOTAL CO_2-eq	**738**	**460 000**	**23 400**	**3 700**
3.2. COMPOSTING TECHNOLOGY (windrow)				
- N_2O	101	63 000	3 200	500
- CH_4	1 295	800 000	40 000	6 500
- CO_2 (biollogical during treatment)	6 064	3 800 000	190 000	30 000
- mineral fertiliser manufacturing	103	64 000	3 200	500
- energy consumption (5 kWh/ton)	76	47 000	2 400	400
TOTAL inc. biological CO_2	**7 638**	**4 774 000**	**238 800**	**37 900**
TOTAL CO_2-eq	**1 574**	**974 000**	**48 800**	**7 900**
4. ANAEROBIC DIGESTION TECHNOLOGY				
-CO_2 content in biogas	1 188	740 000	38 000	6 000
- CO_2 in combustion of methane CH_4	1 638	1 000 000	51 000	83 000
- mineral fertiliser manufacturing	58	36 000	1 800	300
- energy production (CHP) (200 kWh/ton)	-3 742	-2 335 000	-117 000	-19 000
TOTAL inc. biological CO_2	**-858**	**-559 000**	**-26 200**	**70 300**
TOTAL CO_2-eq	**-3 684**	**-2 299 000**	**-115 200**	**-18 700**

Furthermore, another significant feature in emission scenarios is the avoidance of GHG emissions in manure treatment with anaerobic digestion technology. Aeration, composting and storing are causing harmful GHG (i.e.

CH_4, N_20) emissions during the treatment or storing of manure**,** while the anaerobic digestion is not. This is because of the closed treatment environment in AD, i.e. the manure is treated in the closed reactor, in which it is possible to control and monitor the emissions. In addition, the avoidance of nutrient losses, and therefore, the energy need in manufacturing of mineral fertilisers are the lowest when applying anaerobic digestion technology.

When comparing the largest gap between, what can be called as 'throughput-type technology' (i.e. aeration technology) and 'roundput-type technology' (i.e. anaerobic digestion), the difference in National scale is approximately 4.5 million tons of CO_2 equivalents. In the regional level and the local levels, the difference amounts to 230 000 and 37 000 CO_2 equivalent tons respectively.

4.1.3.2 Results of economic scenario

In table 3, direct costs (i.e. manure treatment, energy and mineral fertiliser costs) and indirect (i.e. emission costs) are presented. The time scale in the calculations is set as one year and the pay-back time for the investments of the manure treatment technology is excluded. Note that the investment costs are not included into the calculations, because they would decrease the comparability of the waste management alternatives by determining major part of the economic indicators and hiding the spatial and process-based differences. However, annual operating costs of manure treatment technology are included (including the return of investment) (IPPC 2001a). Therefore, the presentation in table 3 gives only negative monetary values. If only the direct monetary values are included/examined, the storing of manure shows the advantageous (i.e. the most economical) technology whilst reactor composting as well as anaerobic digestion show the most capital-intensive technology (i.e. most expensive). However, if the environmental dimension (emission costs) is included through CO_2 trading[4], the anaerobic digestion is the best manure treatment technology and the aeration technology shows the worst manure treatment technology. Environmental dimension was presented in table 2. At the moment CO_2 trading is in its initial level and only few trades have been made. Furthermore, uncertainty of emission trading, for example in prizing CO_2-equivalent ton and its influence on energy prize are still more or less an open question. However, including the environmental dimension through CO_2 trading becomes meaningful, e.g. in a situation, in which a certain region

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[4] Idea of CO_2 trading in manure management is introduced in Boyd 2000.

(for instance Satakunta) can sell its emissions reduction ability to another region, which, in turn, has notably higher emissions. This is at the moment, however, a highly idealised situation.

Table 3. Direct costs (i.e. manure treatment, energy, mineral fertiliser) and indirect costs from CO_2 emissions from table 2 (CO_2-trade hypothesis).

TECHNOLOGY IN MANURE TREATMENT AND COST PARAMETER	Reference unit (25 tons)	National level 15,6 Mtons (Finland 2002)	Regional level 0,78 Mtons (Satakunta 2002)	Municipal level 0.13 Mtons (Huittinen 2002)
1. STORAGE				
- Manure treatment costs (DIRECT COST)	0	0	0	0
- Energy costs (DIRECT COST)	0	0	0	0
- Mineral fertiliser costs (DIRECT COST)	-58	-36 000 000	-1 800 000	-300 000
Direct Costs total	-58	-36 000 000	-1 800 000	-300 000
- Emission costs (INDIRECT COST)	-149	-93 200 000	-4 700 000	-760 000
TOTAL COSTS/MONETARY VALUE (EURO)	**-208**	**-129 200 000**	**-6 500 000**	**-1 060 000**
2. AERATION TECHNOLOGY				
- Manure treatment costs (DIRECT COST)	-153	-95 500 000	-4 800 000	-800 000
- Energy costs (DIRECT COST)	-18	-11 000 000	-550 000	-90 000
- Mineral fertiliser costs (DIRECT COST)	-55	-34 000 000	-1 700 000	-300 000
Direct Costs total	-226	-140 500 000	-7 050 000	-1 190 000
- Emission costs (INDIRECT COST)	-240	-150 000 000	-7 500 000	-1 200 000
TOTAL COSTS/MONETARY VALUE (EURO)	**-466**	**-290 500 000**	**-14 550 000**	**-2 390 000**
3.1. COMPOSTING TECHNOLOGY (reactor)				
- Manure treatment costs (DIRECT COST)	-337	-210 000 000	-10 500 000	-1 700 000
- Energy costs (DIRECT COST)	-10	-6 400 000	-300 000	-50 000
- Mineral fertiliser costs (DIRECT COST)	-48	-30 000 000	-1 500 000	-240 000
Direct Costs total	-395	-246 400 000	-12 300 000	-1 990 000
- Emission costs (INDIRECT COST)	-49	-30 500 000	-1 500 000	-250 000
TOTAL COSTS/MONETARY VALUE (EURO)	**-444**	**-276 900 000**	**-13 800 000**	**-2 240 000**
3.2. COMPOSTING TECHNOLOGY (windrow)				
- Manure treatment costs (DIRECT COST)	-148	-92 000 000	-4 600 000	-750 000
- Energy costs (DIRECT COST)	-1	-900 000	-46 000	-7 000
- Mineral fertiliser costs (DIRECT COST)	-48	-30 000 000	-1 500 000	-240 000
Direct Costs total	-197	-122 900 000	-6 146 000	-997 000
- Emission costs (INDIRECT COST)	-104	-65 000 000	-3 300 000	-530 000
TOTAL COSTS/MONETARY VALUE (EURO)	**-301**	**-187 900 000**	**-9 446 000**	**-1 527 000**
4. ANAEROBIC DIGESTION TECHNOLOGY				
- Manure treatment costs (DIRECT COST)	-337	-210 000 000	-10 500 000	-1 700 000
- Energy costs (DIRECT COST)	59	37 000 000	1 800 000	300 000
- Mineral fertiliser costs (DIRECT COST)	-27	-17 000 000	-840 000	-140 000
Direct Costs total	-305	-190 000 000	-9 540 000	-1 540 000
- Emission costs (INDIRECT COST)	244	153 000 000	7 600 000	1 240 000
TOTAL COSTS/MONETARY VALUE (EURO)	**-61**	**-37 000 000**	**-1 940 000**	**-300 000**

4.1.3.3 Results of social scenario

The employment opportunities are presented in table 4. The creation of employment opportunities for anaerobic digestion could be over 6000 new jobs in year 2020 in Finland. This is if the European renewable policy (e.g. the European Commission White Paper, Action Plan on Renewable Energy Sources) is undertaken as predicted (McNally, 2001). If all renewable technologies (e.g. wind power, biomass combustion, fuel production, energy crops etc.) are put together, it is possible to create over 30 000 new jobs in Finland.

Table 4. Results of employment scenarios of renewable energy production after McNally (2001)

Technology	Number of new jobs		
	in year 2005	in year 2010	in year 2020
All renewable technology	20695	26071	30592
AD Technology	4139	5214	6118

In implementing AD technology in agriculture, new jobs arise mainly from construction and installation of the technology (i.e. biogas reactors, pumps, CHP engines, biogas storage etc.). In addition, operating and maintenance of the technology creates new employment opportunities. When evaluating the other manure treatment technologies, there are opportunities for employment also. For instance, reactor composting and aeration require construction, installation, operating and maintenance like anaerobic digestion does. Windrow composting and storage are not labour intensive technologies comparing to AD and reactor composting.

4.1.4 Discussion of the model I

In this chapter, the above presented model is discussed. In this model, the objective was to evaluate the differences of four alternatives to manure treatment. As noted above these presented results are only point given, not an absolute result.

In Finland, there are some calculations of CH_4 and N_2O emission potentials in manure treatment. In the Finnish report (Pipatti 2001) GHGs in manure treatment are lower that presented in this study. The report presented CH_4 emissions from manure treatment of 200 000 tons of CO_2 – eq and N_20 emissions of 600 000 CO_2 – eq, while this study presented of 560 000 CO_2 – eq through CH_4 and 840 000 CO_2 - eq through N_2O. There are following reasons for the differences of presented CO_2-equivalents. First, methodological background of the calculations is different. Pipatti (2001) has used general method adapted from (IPPC 1995) while we have used scientific journal publications and average data of different publications presented in the Journals. Second, climatic differences in our calculations are mainly excluded. This is because some laboratory scale analysis on determining the emissions of CH_4 and N_2O was carried out in the referred Journal articles.

These differences in emission parameters, of course, would change the economic scenario results considerably. Furthermore, energy prize and CO_2-equivalent prize are estimated in this study. These are discussed also in the appendix I.

There are other similar studies than presented in this study. For instance in certain studies in Finland (Pipatti et. al. 1996) anaerobic treatment has been acknowledged less harmful than composting, because in AD produced energy can replace the fossil fuel produced energy. Furthermore, an Austrian study made by Edelmann et. al. 2001 compared using the LCA of composting, anaerobic digestion and incineration of biosolid waste treatment. In the study of Edelmann et. al. 2001, anaerobic digestion was better biolocical treatment compared to composting with perspective of acidification, GHG potential and energy balance. Baldasno & Soriano 2000 studied the AD with incineration, composting with incineration and incineration of biosolids. The highest GHG potential was incineration and lowest was anaerobic digestion with incineration. These studies support here presented argument that anaerobic digestion is in line with roundput and again as understood with our two criteria of energy efficiency and emission intensity.

Anaerobic digestion (AD), as an alternative energy source, would provide an essential surplus to renewable energy field especially with cold climate country as Finland. In addition, there are also other reasons behind the AD, such as hygiene (destroying pathogens) of manure, and the prevention of bad odours, which are difficult to measure in environmental or economic point of view. These issues would need different monetary weighting studies and methodology, e.g. willingness to pay and other social studies. Furthermore, issues including hygiene aspects in storage, aeration and composting are excluded in this study, which will make the energy balance more negative, because of the need for extra energy need in these technologies or treatment options. These changes, of course, would change the energy balance of the calculations.

According to European Climate Change Programme 2000, the AD technology provides a major reduction potential to GHGs in Europe. The total GHG savings according to this report would be 17 M t CO_2-eq annually by favouring AD technology. Nevertheless, cost effectiveness is so far low in AD-plants and so is the general knowledge of how run the plants with good results. Consequently the EU report estimated the realistic "cost effective"[5] potential around 1,7 M t CO_2-eq annually (COM(2000)88).

Furthermore, the potential of using biogas as fuels for vehicles should be mentioned. The use of biogas to replace fossil fuels in vehicles has been claimed to provide the highest reductions in greenhouse gas emissions[6]. This alternative, however, depends very much on developments in the energy and transport sector in the EU.

4.2 Case study II: Satakunta region waste management system

4.2.1 Objective and scope

Paper II presents the case and prepares an initial environmental and economic review for the waste flows in the Satakunta region. In the Satakunta case area, most of the smaller landfills in the individual municipalities will be closed in the near future. This leads to the situation in which the transportation distances to few larger landfills e.g. that of the Pori city is rising dramatically. The aim of the study was to evaluate the possibilities to use locally derived wastes in decentralised waste management instead of centralised waste management junctions. In addition, different waste management options were compared.

The case region encompasses 12 municipalities of which eight are situated in the Satakunta region and the remaining four in the Pirkanmaa region (see figure 5). The region is located in Southern/South-Western Finland. The population of the area is approximately 70 000 inhabitants. The area consists of small towns with a large rural area where the main activities are agriculture and food industry. More detailed information of the case region is presented in Table 5.

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[5] Cost effective AD depends of factors of CH_4 production rate, additional products (wastes) to digest, investments etc and may be "utopia" for next years without a substantive subsidy on investment and subsidy of "green energy" (COM(2000)88)

[6] There are many examples of case studies and biogas use with vehicle fuels for instance in Sweden (for case studies and discussion see for example Eriksson et. al. 2003)

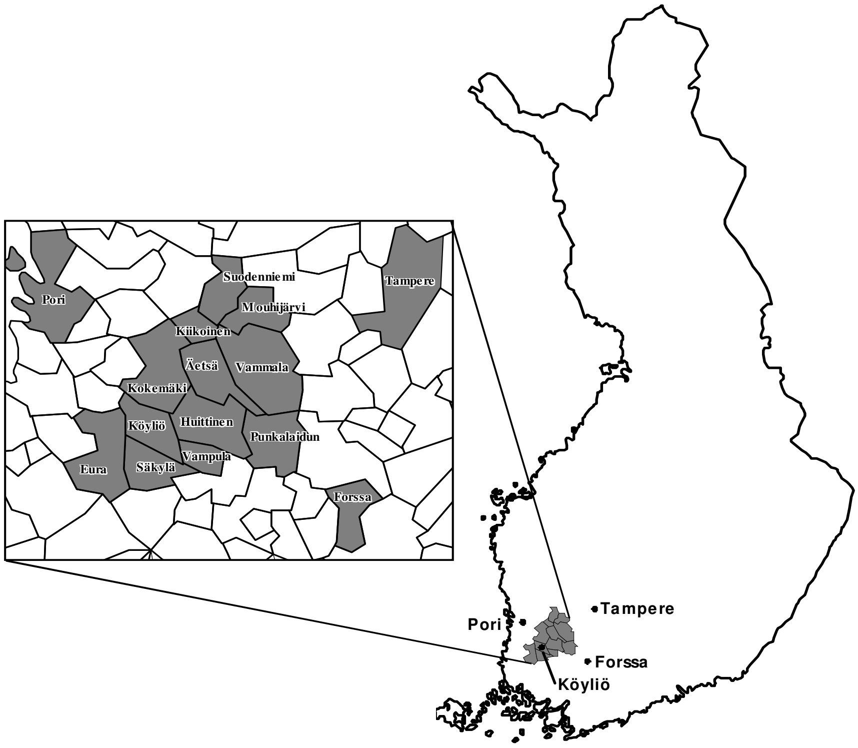

Figure 5. Satakunta case area**.**

Table 5. Satakunta case area in numbers.

Municipality	Population total	Urban population %	Area km^2	Co-operation in waste management	Transport distance of wastes
Huittinen	9207	72	395	Pori	64
Punkalaidun	3743	40	364	Forssa	47
Köyliö	3010	49	259	Hallavaara	0
Säkylä	5108	43	268	Hallavaara	7
Kokemäki	8714	64	532	Pori	42
Vampula	1776	34	144	Pori	80
Vammala	15450	74	656	Forssa	78
Mouhijärvi	2879	48	268	Pirkanmaa	58
Äetsä	5075	77	241	Forssa	103
Suodenniem	1428	40	220	Pirkanmaa	45
Kiikoinen	1349	30	144	Forssa	103
Eura	9453	74	480	Hallavaara	12
TOTAL	**67192**	**54**	**3971**		**53**

4.2.2 Method and used data

Paper II presents 'what if' scenarios that serve to show what the future of the waste management system could look like with different approaches to the waste management effort. Paper II presents mainly environmental data, but also some economic factors, e.g. costs, are discussed. The "what if" scenarios can pose a provocative question for regional decision-makers, both public and private, such as 'Where do we want to go?'

In Figure 6, the waste material and energy flows of the Satakunta regional case study are presented. The focus is on two different categories of the waste flows. The categories are the biowaste flows (A) and waste flows suitable for incineration (energy waste) (B). Biowaste consists of household biodegradable waste (1), industrial wastes that mainly originate from food processing industry (2), agricultural waste, which is mainly manure (3) and wastewater treatment sludge (4). Energy waste (EW) fractions consist of combustible household waste (1), industrial waste (2), agricultural and forestry waste (3).

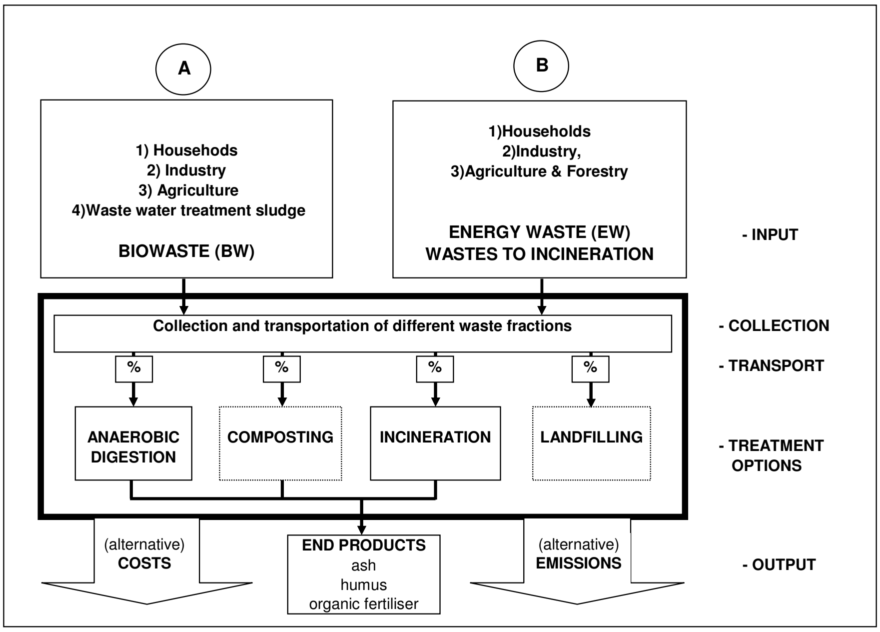

Figure 6. The studied processes and flows in the Satakunta region waste management system

The collection of household wastes and transportation of household and industry wastes (i.e. municipal mixed wastes) with alternative distances into treatment sites are calculated. The weighting (%) between possible treatment options is acknowledged (i.e. different treatment methods can be compared with each other and the amount of wastes can be divided into different waste treatment alternatives). Treatments of wastes are divided into four alternative scenarios:

- anaerobic digestion (biogas production) for biowastes,
- composting for biowastes,
- incineration for combustible fractions and
- landfilling of wastes.

Material and energy balances as well as emissions are calculated with transportation and different treatment scenarios. The duration (functional unit) of the calculations is defined as one year (i.e. the amount of wastes which are generated during the period of one year).

Alternative costs and alternative emissions from different transport distances as well as waste treatment options are the main outputs from model II. However, landfilling has been excluded from emission calculations, because of uncertainty of emissions, especially with a period of one year. The decay of organic matter in landfills is difficult to model and calculate, especially in the period of one year. For instance, landfilled biowastes continue the decay process under anaerobic conditions for 20 – 50 years (Barlaz et. al. 1990, Jokela 2002). Therefore, because of the uncertainty of emission parameters, landfill emissions are excluded from this study. In addition, within a few years the municipal landfills are going to be closed in the case area (except the municipal landfill of Hallavaara in Köyliö).

The data used, calculation methods, limitations and assumptions of model II are presented more detailed in appendix 2.

4.2.3 Results

4.2.3.1 Results of environmental scenario

The focus in article II is on biodegradable waste and energy waste flows, which are possible to treat locally in smaller treatment units (decentralised treatment, mainly scale of a farm) or regionally in larger treatment units with emphasis on energy production. The biowaste and energy waste flows of various sources are presented in table 6.

Table 6a. Bio- and energy wastes and energy production

Municipality	BIOWASTES: Agriculture biowaste	BIOWASTES: (Food) industry biowaste	BIOWASTES: Municipal biowaste	BIOWASTES: Waste water treatment sludge	ENERGY WASTES: Agric.-Forestry energy waste, m^3	ENERGY WASTES: (Food) industry energy waste	ENERGY WASTES: Municipal energy waste
Huittinen	78 000	3 400	1 100	2 500	11 500	1 400	1 700
Punkalaidun	55 000	140	400	1 400	13 000	400	600
Köyliö	26 000	900	300	400	7 200	400	500
Säkylä	10 000	14 000	500	1 400	5 700	400	800
Kokemäki	10 500	8 200	860	1 700	19 300	1 200	1 400
Vampula	64 000	60	200	200	2 900	200	300
Vammala	67 000	2 700	1 800	4 000	16 800	2 400	2 800
Mouhijärvi	14 000	100	300		6 500	300	500
Äetsä	38 000	300	700	1 200	6 500	700	1 100
Suodenniemi	30 000	50	100	300	5 800	200	200
Kiikoinen	20 000	50	100	400	5 100	100	200
Eura	36 000	1 300	940	1 600	15 000	1 600	1 500
TOTAL (ton)	**448 500**	**31 200**	**7 300**	**15 100**	**115 300**	**9 300**	**11 600**
Energy in biowaste (MWh)					**Energy in waste (MWh)**		
a) Anaerobic digestion	**103 000**	**8 600**	**11 000**	**5 500**	**-**	**-**	**-**
b) Composting (reactor)	**-15 700**	**-1 000**	**-250**	**-500**	**-**	**-**	**-**
c) Combustion	**-**	**-**	**-**	**-**	**150 000**	**45 000**	**55 000**

Table 6b. CO_2-balance – renewable fuels (inc. wastes) vs. fossil fuels

Technology	Biowaste(s) MWh total	Biowaste(s) CO_{2eq} ton	Fossil fuel CO_{2eq} ton	Technology	Agric.-Forestry waste MWh total	Agric.-Forestry waste CO_{2eq} ton	Fossil fuel CO_{2eq} ton	Technology	Energy waste MWh total	Energy waste CO_{2eq} ton	Fossil fuel CO_{2eq} ton
AD	128 100	0	2 754	**Combustion**	150 000	0	3 225	**Combustion**	100 000	538	2 150
Composting	-17 450	0	375								

In table 6a (on the left-hand side), the different biowaste (BW) flows are presented with the energy production of waste. It is assumed here that anaerobic digestion treatment method or reactor composting technology is used. Anaerobic digestion technology is able to produce energy, while composting requires energy. The difference between energy balance with these two technologies in the Satakunta case region is 145 000 MWh. Produced energy (or consumed in composting) is compared with fossil fuel production of the maximally produced energy in anaerobic digestion (128 100 MWh) and furthermore emissions through CO_2 are presented. Through renewable basis of biowastes in anaerobic digestion, energy production emissions are neutral, i.e. the CO_2 emission is zero, while composting, energy produced with using fossil fuels gives CO_2 emissions of 375 tons (composting requires energy, produced with fosil fuels), and 2754 tons (produced energy in AD and it avoidance of the fossil fuel produced energy) (see table 6b).

A biowaste emission of zero is set, because carbon is binded into a biomass and released back as CO_2 in the atmosphere through biogas. Similarly, in the Finnish forest ecosystem, where the annual cuttings are less than the growth of the forests, the forest ecosystem is able to bind more CO_2 than the amount of carbon that is released from the forests through cuttings and natural drainage (Kauppi et. al. 1992, Korhonen et. al. 2001).

In table 6a (on the right-hand side), the different energy waste (EW) flows are presented with energy consumption in waste treatment. Produced energy is, then, compared with fossil fuel production of the maximally produced energy of energy wastes in the cases of (A) agriculture and forestry waste (energy content of 150 000 MWh) and (B) energy wastes from households and industry (energy content of 100 000) MWh) in the case region of Satakunta. Similarly as in the case of biowastes, emissions through CO_2 are presented. Renewable basis in agricultural and forestry waste (mainly wood based renewable materials) is emission neutral, i.e. the CO_2 emission is zero, whilst same energy content produced in fossil fuels gives CO_2 emissions of 3225 tons. In the case of household and industry energy wastes the CO_2 emissions are 538 tons, while same energy content with fossil fuels gives CO_2 emission of 2150 tons[7].

In the table 7, the energy input and emissions output flows of transportation of waste fractions from households are presented.

[7] It is assumed here, that energy waste from end-consumption and food industry includes some fossil fuel origins, e.g. plastics in packaging etc. Therefore, the emissions is ¼ of the fossil fuel scenario (Korhonen 2000)

Table 7. Collection and transportation of (municipal) wastes: (A) when transported to centralised landfills ("distant landfills"), (B) when treated locally

	"distant landfills"		"local treatment"	
Municipality	**Input energy A (distant treatment) MWh**	**Output emissions A CO_2, kg**	**Input energy B (local treatment) MWh**	**Output emissions B CO_2, kg**
Huittinen	360	29 000	60	6 000
Punkalaidun	50	4 500	10	1 400
Köyliö	0	800	3	800
Säkylä	20	1 800	5	1 100
Kokemäki	170	14 000	30	3 700
Vampula	40	3 000	7	800
Vammala	760	58 000	120	11 000
Mouhijärvi	50	4 000	10	1 200
Äetsä	330	25 000	50	4 700
Suodenniemi	39	2 100	5	560
Kiikoinen	20	1 400	3	500
Eura	70	6 600	20	2 800
TOTAL	**1 900**	**150 000**	**330**	**35 000**

Through relatively long transport distances of bio- and energy wastes (see also table 5 and figure 5) to distant centralised treatment (A), the input energy (1900 MWh) and output emissions (150 000 CO_2) are approximately 5 times greater than in the case of local (B), decentralised treatment (input energy of 330 MWh, output emissions 35 000 CO_2).

Consider now the section of the thesis that covers the throughput and roundput concepts. For the purposes of the conceptual presentation, anaerobic digestion technology seems to be in line with the roundput-type material and energy flow model, and again, when analysed against our two criteria of energy efficiency and emission intensity. It is able to use the energy value in biowastes. The option for treatment of biowastes, composting, is not able to produce energy. The produced energy in anaerobic digestion with comparison to fossil fuels use shows the cyclic roundput model. Anaerobic digestion is able to recover the energy of waste flows, i.e. as in the cyclical and cascading roundput model. Incineration of energy wastes is also a roundput type method of energy production; while the use of fossil fuel based fuels are throughput types. In addition, the decentralised treatment of the bio- and energy wastes is in line with roundput type of an activity in the Satakunta waste management case area when measured in energy efficiency and emission intensity.

4.2.3.2 Results of economic scenario

In the Satakunta case area, most of the smaller landfills in the individual municipalities will be closed in the near future. The transportation distances to few larger landfills, e.g. that of the Pori city, and the issues related to waste treatment or landfill costs are presented in table 8.

Table 8. Difference between the landfill treatment of municipal waste and locally treated municipal wastes for energy use in terms of regional economic effects.

Municipality	Collection and transportation costs 2001	Waste treatment costs 2001	Collection and transportation costs BA	Waste treatment costs BA
Huittinen	124 000	163 000	83 000	28 000
Punkalaidun	28 000	57 000	22 000	10 000
Köyliö	29 000	46 000	22 000	8 000
Säkylä	46 000	78 000	34 000	13 000
Kokemäki	84 000	132 000	64 000	23 000
Vampula	13 000	28 000	8 000	5 000
Vammala	223 000	384 000	136 000	66 000
Mouhijärvi	24 000	53 000	49 000	9 000
Äetsä	86 000	148 000	18 000	25 000
Suodenniemi	10 000	23 000	7 000	4 000
Kiikoinen	9 000	29 000	7 000	5 000
Eura	110 000	143 000	81 000	25 000
TOTAL (MEURO)	**0,8**	**1,3**	**0,5**	**0,2**
Difference/save (MEURO)	**(reference)**	**(reference)**	**0,3**	**1,1**

In table 8, the difference between local treatment and energy use and the treatment of waste in a few larger landfills are presented. The situation in 2001 is assumed, that 90 % of municipal and industrial bio- and energy wastes are collected, transported and treated in distant landfills of Pori, Forssa or Hallavaara. In the best available (BA) situation (scenario), it is assumed that only 10 % of municipal and industrial bio- and energy wastes are collected and treated in distant landfills and 90 % of wastes are treated locally in decentralised waste treatment plants. Therefore, individual municipalities could in theory gain by investing in energy production that relies on waste utilisation as fuels. These fuels are local wastes and these will not have to be transported to distant landfills. The investment costs of energy plants can of course be relatively high, although much of the technology and techniques are already in place. Nevertheless, the operational costs of continuing transportation to distant landfills and the landfill costs may prove to be more costly in the long run[8].

4.2.3.3 Results of social scenario

In implementing AD technology in biowaste treatment, new jobs arise mainly from construction and installation of the technology (i.e. biogas reactors, pumps, CHP engines, biogas storage etc.). In addition, operating and maintenance of the technology creates new employment opportunities as previously presented with model I. However, clear numerical data is very difficult to present here, because of uncertainties in the estimations of the scale of the technology in the Satakunta case region. When evaluating the other biowaste treatment technologies, there are opportunities for employment also. For instance, reactor composting requires construction, installation, operating and maintenance like anaerobic digestion does.

Incineration of energy wastes creates new opportunities for employment similarly as described above with biowaste treatment technologies.

4.2.4 Discussion of the model II

There are similar or related studies in the international scientific literature where regional waste management have been studied. In Finland, for example, Isoaho & Vinnari 2003 and Tanskanen (2000) and in Sweden Eriksson (2003) and Björklund (2000) have studied municipal waste management from a systems perspective. These studies were performed by using data of relatively densely populated areas (e.g. metropolitan and relatively large city areas of Finland and Sweden) while Satakunta case area is more or less rural area. Therefore, for instance, the transportation distances have not played an essential role in above-mentioned studies. Isoaho and Vinnari (2003) studied centralised, partly centralised and decentralised regional options jointly for biowaste and sludge management in the Pirkanmaa region from system and cost-benefit perspective. With several variations of each system, Isoaho and Vinnari (2003) studied total 34 regional system options for biowaste management. System options were based mainly on end product quality, environmental impacts of waste

[8] The presented cost savings in transportation of wastes and treatment costs are calculated by using the situation in 2001. However, especially the treatment costs of wastes will increase considerably within few years, which support the presented arguments.

treatment, energy balances of different treatment alternatives (i.e. composting, anaerobic digestion and incineration) and cost-analysis of different biowaste treatment options. Based on their results, the transportation cost is not a significant factor. The most significant factors seem to be the hygienic and other qualities and the final destination of the end product. In addition, an important factor in choosing the biowaste treatment processes is the management of their operational performance and environmental impacts. As a result of "system and cost-benefit analysis of sewage sludge and biowaste management options in the Pirkanmaa region" by Isoaho and Vinnari (2003), they suggested that centralised anaerobic digestion treatment option for wastewater treatment slugde and biowastes with additional thermal treatment would be the best alternative.

Eriksson (2003) and Eriksson et. al. (2003) studied engineering models for waste management systems and energy systems. The scenarios including waste incineration with only heat production gave the lowest costs, followed by co-combustion of biofuel and separated waste and waste incineration while combined heat and power (CHP) showed highest costs. The lowest emissions of GHGs were obtained in the scenarios where a new base load plant was assumed to be a heating station or a combined heat and power plant (CHP) with biofuels. Furthermore, they found that, incineration and anaerobic digestion are complementary methods that should be used maximally with the benefit of decreased landfilling. In biowaste treatment, the most cost-efficient solution could be found when biogas from digestion was used as fuels in cars. In terms of eutrophication potential, anaerobic digestion is worse than incineration due to problems related with the agricultural technology of today. However, in the future Sonesson et. al. (2003) suggested, when organic waste fractions are banned to deposit at landfills, incineration and digestion complete the organic waste management. In this situation, incineration and digestion are favourable in terms of economy (financial and environmental), eutropfication and energy turnover.

Suh and Rousseaux (2002) studied LCA of the alternative wastewater sludge treatment scenarios in the European context. The scenarios were composed of one main process (incineration, agricultural land application or landfill), one stabilisation process (lime stabilisation, composting or anaerobic digestion) and transports of sludge. The study results showed: the combination of anaerobic digestion with agricultural land application was the most environmentally friendly solution due less emissions and less consumption of energy compared to other possible solutions.

4.3 Case study III: Landfill management system

4.3.1 Objective and scope

In Finland, the majority of the present and functioning landfills are closed within 5-10 years. Now there are approximately 250 – 300 municipal or industrial landfills in Finland and it is estimated that the number will be reduced to 50-80 by the year 2005 (Ministry of Environment 1998, Tanskanen 2000).

Paper III considers a method that can be used when closing old landfills. The method relies on the use of paper industry waste flows, on wastes that occur when used paper is recovered and de-inked to make the recovered mass fit the production cycle of paper again as well as on wastes from forest industry energy production. These waste flows serve to substitute the use of natural clay in landfill building. The aim is to consider whether this method is preferable to the existing practices of using natural clay and manufactured materials (e.g. geomembranes) for building landfill cover layers.

4.3.2 Method and used data

The closing of old landfills typical in Finland is presented in figure 7. The surface structure of a closed landfill is divided into variable layers (top-down), vegetative cover layer, drainage or leachate collection layer, impermeable layer and landfill gas collection layer. Perhaps the most important or crucial one is the impermeable layer. This layer has to fulfil the requirements of the hydraulic conductivity, the k-value ($k < 1 \times 10^{-8}$ in general) and the thickness of at least 0,5 m. Wood based fiber sludges such as fiber clay and de-inking sludge as well as energy production wastes (ashes) are especially suitable for impermeable layer material. Natural soils such as clay, silt and sand bentonite mixes are the most used ones in final cover systems. Also geosynthetic materials such as geomembranes are widely used (Saarela 1997). In model III, the focus is on impermeable layer.

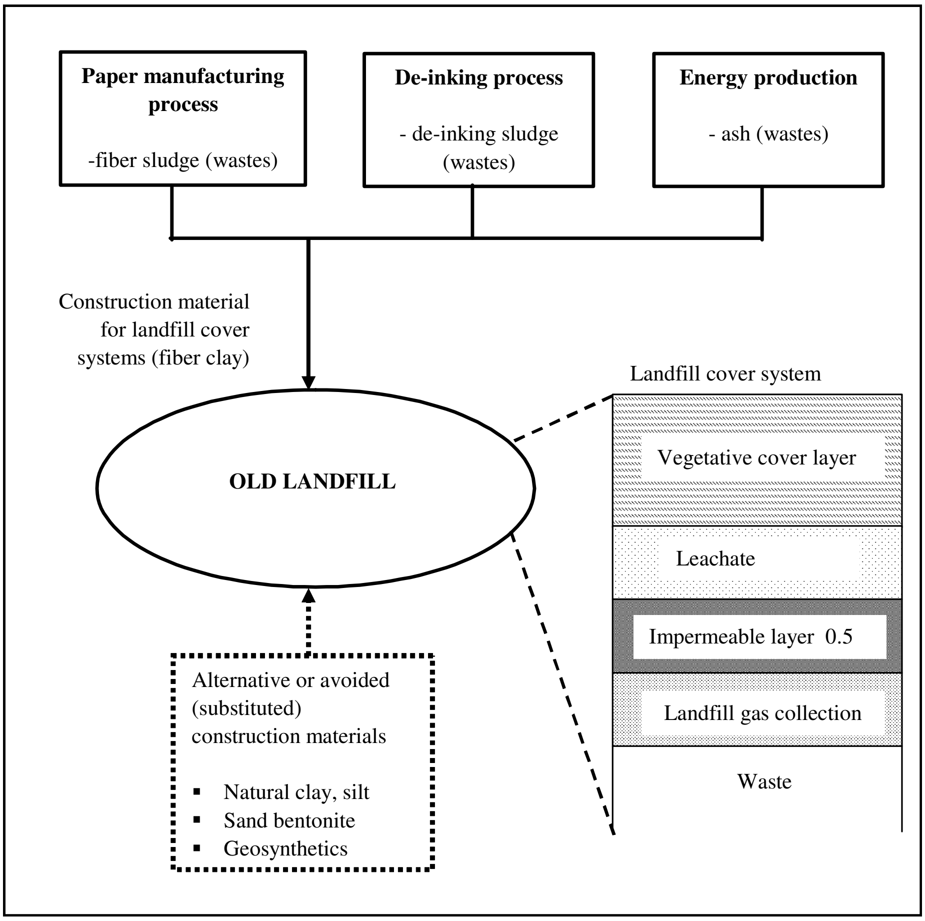

Figure 7. Landfill cover system and alternative construction materials

Figure 8 presents, then, the scenario approach with different construction materials suitable for impermeable layer. The construction materials are compared by using four different scenarios A – D. In scenario A, the simplified construction route is presented with fiber clay and ash[9]. When using the natural materials or resources such as natural clay (B) or sand bentonite (C), the construction method is quite similar; first extraction

[9] In the calculations of energy consumption of the alternative materials, the emphasis is placed on evaluating the performance of paper manufacturing and energy production side-products when compared to other suitable materials for landfill closure process, not the paper manufacturing process itself. The paper manufacturing process in itself is relatively energy intensive and would hence change the results considerably.

and digging the construction material, following with the transportation to landfill, and finally at the landfill, spreading and compressing the material. When using artificially manufactured materials such as geomembranes (D), the construction method is more complex. The geomembrane is itself only 2 millimetres thick and there is a need to use filling material such as sand etc. to fulfil the requirements in legislation (thickness of at least 50 cm) (Council of state decision 861/1997). The manufacturing of geomembrane consists of manufacturing the plastic material and geomembrane itself as well as various requirements for transportation. The actual steps included in the calculations are marked with colour in the figure 8.

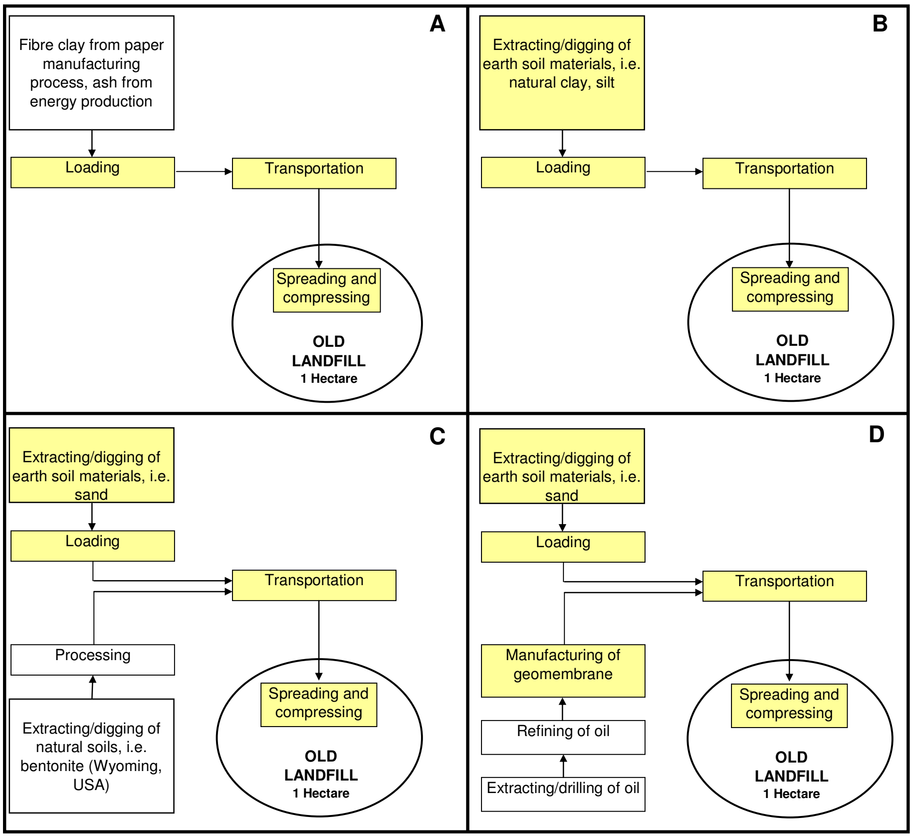

Figure 8. Scenario approach for constructing the impermeable layer for closed landfill with A) Waste materials (fiber clay, ash); B) Natural soils (clay, silt); C) Sand bentonite; D) Geomebrane. In the scenario calculations the marked stages of the construction process are included.

The data used, calculation methods, limitations and assumptions of the model III are presented in appendix 3.

4.3.3 Results

4.3.3.1 Results of environmental scenario

The results of calculations for the comparison of energy use and emission generation of different material alternatives and techniques for landfill impermeable layer construction are presented in table 9.

Fiber clay scenario/method for impermeable layer of landfill cover system uses less energy and produces less emissions than other construction materials and methods. Fiber clay materials consume 2,5 times less energy than natural clay materials, 6,6 times less than sand bentonite structure and 22,9 times less than a geomembrane structure in the construction on a one hectare of impermeable layer of closed landfill structure. Therefore, for our conceptual presentation, the fiber clay method seems to be in line with a roundput type, while sand bentonite and geomembrane structures are a throughput type. Again, our criteria were simplified and defined to focus on energy efficiency and emission intensity.

Table 9. Energy input and emission output of various materials when constructing impermeable layer on a closed landfill (area of one hectare) (Niutanen 2000).

Construction material	Input Energy (kWh)	Output emission CO_2 (kg)	Output emission NO_x (kg)
Fiber clay	10 200	8300	100
Natural clay	25 200	20 000	240
Sand bentonite	66 900	42 000	1200
Geomembrane	229 900	37 000	240

4.3.3.2 Results of economic scenario

In Finland, annually about 600 000 tons of fibre sludges are produced. The normal and prevailing method of de-inking sludge waste management is incineration and landfilling as mentioned in previous chapter. The disposal of this amount of paper industry residues requires approximately 10 hectares of industrial landfilling space each year. Therefore, one can calculate the cost of landfilling of paper sludges, which is depended on the following factors:

- Costs of bottom lining and cover system in an industrial or municipal landfill, 70 €/m^2
- Waste tax, 15 €/ton
- Transport, 5 €/ton (transport of 25 kilometers)

Including the above costs, paper sludge disposal costs to industry is about 19 million Euro annually, which would be mostly avoidable if the paper sludge material is used for instance in landfill construction material. As noted in the introduction, approximately 250 –300 municipal or industrial landfills are being closed in Finland in the near future (between five to ten years). The average size of these landfills is approximately 2 hectares (Karhu 1997, Tähtinen 1999). Furthermore, cost savings in landfill constructions are dependent on savings through construction materials. In table 10, some suitable materials for landfill liners with unit prices are presented.

Table 10. Economical parameters of suitable construction materials for impermeable layer on old landfills

MATERIAL	**UNIT PRICE (euro / m^2)**	**PRICE (€) IN CONTRUCTION (1 ha)**
Fiber clay	7	70 000
Natural clay	6	60 000
Sand bentonite	18	180 000
Geomembrane	17 - 20	170 000 - 200 000

4.3.4 Discussion of the model III

As noted in the beginning, approximately 250 –300 municipal or industrial landfills are being closed in Finland in the near future (between five to ten years). Average size of these landfills is approximately 2 hectares (Karhu 1997; Tähtinen 1999). Then, the total amount of material required for impermeable layer is approximately 3 million m^3. In Finland, the forest industry produces 400 000 tons (dry weight) of fiber clay and 170 000 tons (dry weigh) of de-inking sludges annually, which equals roughly 900 000 m^3 annually[10]. When comparing these figures, it can be argued that hypothetically, it is possible to cover all of the demand for landfill impermeable layer materials with wood based sludge material, i.e. fiber clay

[10] Density of the fiber sludge is 600 kg/m^3

or fiber sludges as well as de-inking sludges. Considering this, massive energy saving possibilities arises and output emissions are reduced.

The described landfill management method can also eliminate large parts of the difficult incineration ash waste streams (cadmium content) of the forest industry energy production, because the ash can be used in the end-treatment of landfills. The method requires less energy than the use of natural clay, sand bentonite or geomembrane.

There are many other environmental advantages in waste and fiber clay utilisation for landfill construction. The utilisation of wastes in the building of landfill structures substitutes the use of scarce and non-renewable natural soil reserves for the same purpose. Natural soils are taken from an ecosystem (mostly ridge areas). This may result in various environmental problems such as ground water contamination and disturbance of valuable natural habitats (Lahtinen 2001, Haavikko 1998).

Fiber clay and de-inking residues have usually been treated in incineration plants (e.g. co-production plants of heat and electricity, CHP) or transported to landfilling. However, for instance, incineration has not been a particularly environmentally or economically efficient solution, because of low caloric heat value of 12 kJ/kg (Moo-Young & Ochola 2000). There is also a problem with incineration of paper sludges, because of high content of water in it. Before the actual incineration process, the fiber material has to be pre-treated with belt presses etc., which consume extra energy. Also the landfill treatment of fiber clay has been difficult. It has been very difficult to utilise the material content in it and it has been filling the landfills, the space of which is becoming more limited in the near future.

There are similar or related studies in the international scientific literature where paper mills are seeking cost-effective and environmentally sound management strategies for their de-inking sludge disposal. For example, Nikiforuk 2000, Goldstein 1999, Engel and Moore 1998, Fwyer 1998 and Hauser Jr 1998 have reported on North American trends in paper sludge management. According to these references, there is a clear trend away from landfilling the de-inking residues. The reason is that more stringent landfill regulations and siting difficulties lead to a higher capital and operating costs. In these references the use of de-inking residues for landfill cover and closure has been adapted by a number of paper mills, facilitated by special regulatory provisions allowing the use of alternative cover materials in landfill operating permits. Many paper mills, that currently landfill their de-inking residues, have indicated that they are actively considering alternative management strategies. For most paper mills, the high cost of building and operating a new landfill forces them to consider other options.

As mentioned previously, the sludge replaces the compacted/natural clay, which is usually used as the impermeable barrier layer. This is an especially successful use of paper sludge, since landfill covers use large quantities of sludge. Since the paper sludge is provided at little or no cost to the landfill covers, saving the cost of compacted clay, typical savings of 50 000 – 100 000 US $ per hectare, which equals more or less same in €, have been achieved (Zimmie 1997, Moo-Young Jr. 1995). This of course is an economic "win-win" situation for the paper companies and the landfill owners (typically local taxpayers)

However, most paper mills generally do not consider landfill cover to be a viable long-term solution. When landfills in the certain area are closed, there will be no more need for de-inking residues. Therefore, other applications and strategies are needed and some of these are listed in the following:

- Material for road construction (Lahtinen 2001, Haavikko 1998)
- Material for fugitive dust emission material for mining operations (Vitton 2000)
- Material for reactive barrier for contaminated groundwater (Moo-Young & Ochola 2000)

4.4 Case study IV, research paper of general and conceptual discussion on agrofood Industrial Ecology

4.4.1 Objective and scope

The objective of the paper was to consider the applicability of the natural ecosystem metaphor to agricultural and food industry system. The case studies to provide quantitative evidence for the usability of this approach to sustainable development, however, remain few. The objective of this paper is to consider the applicability of the natural ecosystem metaphor to agricultural and food industry systems. We will show that the metaphor can help us in being creative and it can give us inspiration. This creativity and inspiration can direct us towards thinking from which, eventually, more practical models can emerge. At this point, I must emphasise that metaphor of natural ecosystems is only the source of thinking and creativity, when constructing practical models, not the practical models themselves.

The focus in paper IV will be on scavengers and decomposers in the natural ecosystem metaphor: these organisms of ecosystems can both take in wastes from other organisms and produce useful materials for them to use. The metaphor is applied to a case study of a regional agricultural and food industry system. The calculation data is same than presented in model II.

4.4.2 Results and discussion of paper IV

Our literature review and case study scenario analysis yields three main results. First, the natural ecosystem metaphor is beneficial to study the physical flows of matter and energy. The metaphor can yield models with which a vision of a more sustainable material and energy flow system can be constructed. Second, the difference of ecosystems and economic systems is still so radical, that, at best, the ecosystem metaphor can be used as a source of inspiration for simulations and future scenarios, not for giving practical management or design objectives and action-proposals for current day challenges. Third, the data and methodology used in this study cannot show evidence that the metaphor could be used to study the human dimension or the societal context of the material and energy flows. These results imply that the natural ecosystem metaphor, at this stage of development in the literature, is best suited for engineering studies, material and energy flow systems analysis and inventory analysis not for construction of practical management, organisational or policy principles and programmes.

5 DISCUSSION

5.1 Throughput and roundput material and energy flows and the limitations of this definition

By using “what if” scenarios, related material and energy flow tools, throughput and roundput technologies and methods have been presented. In model I, the roundput type technology in the agricultural waste management, was defined as anaerobic digestion. In model II, the local decentralised treatment of waste flows by using anaerobic digestion for biowastes and incineration for energy wastes was defined as roundput type technique in regional waste management. In model III, use of waste and side product flows from forestry and energy production industries was defined as roundput in old landfill closure management. The criteria were as follows; high energy efficiency and low emission intensity for roundput and opposite, low energy efficiency and high emission intensity for throughput.

The presented throughput and roundput flows and technologies, however, are not absolute in the terms of quantifying and qualifying of the regional waste flows. In many cases, the weighting of the calculations, limitations and assumptions of the data used may be dependent on, for instance, the definition of system boundaries or even by the person who has built and calculated the scenarios. Therefore, different results may be presented, for instance, by expanding the system boundary or by expanding the time horizon or by “using” a different researcher.

For example, in model I, the fertiliser recovery was evaluated. However, fertilising efficiency in arable fields was excluded from the calculations and, therefore, this may have changed the results of the presentation. Fertilising efficiency through the treatment of manure with different technologies (i.e. storage, aeration, composting, anaerobic digestion) and the spreading of treated manure may be dependant on various variables in arable fields. Figure 9 gives an overview of the situation of the fertilising efficiency and variables of these changes that should to be considered.

The input of nitrogen and availability of plant intake of nitrogen is dependant on among other things, bacterial activity of the ground, ground structure, weather conditions etc. All the features together are dynamic and may vary on a daily basis. Therefore, to be able to define the efficiency of fertilising recovery through different treatment technologies, field cultivation tests are needed in the different weather conditions and different areas in

Finland. Importance arises in Finland, because only few cultivation tests have been made in arable fields. Mostly, cultivation tests in Finland are performed in the laboratories, only simulating the "real" situation (see e.g. Salminen et. al. 2001).

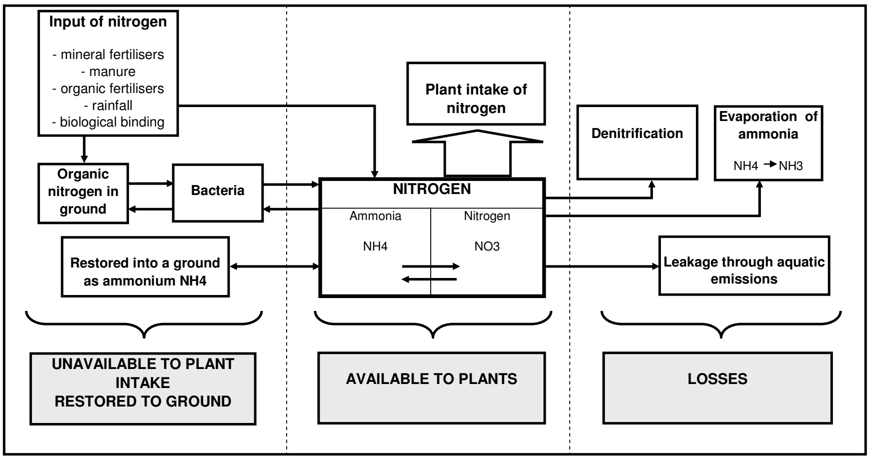

Figure 9. Aspects of fertilising efficiency in arable fields (Valpasvuo-Jaatinen 1998)

However, even incomplete information is important for a decision-making process in "designing for the future" or designing sustainable regional waste management. Therefore, the potential of roundput material and energy flow analysis is an initial starting point for designing the environment and industrial park visions.

The calculation models used in this thesis are simplified and can be created in the format of spreadsheets. Excel 97 was used in models I and II. Model III was achieved by using a special LCA calculation model, which is, however, able to perform as Excel spreadsheet. When describing large systems with various processes such as regional waste management, spreadsheets are effective and flexible tools.

In the regional waste planning, flexibility is the key factor (Solem & Brattebo 1999), because modern and future planning questions to be answered vary a lot and depending on assumptions regarding technological issues. For instance, the perspectives of environmental, economic and social dimensions must be taken into account simultaneously. Consider tables 2 and 3, in which the AD was ranked as an expensive waste treatment alternative and then, when the environmental dimension was included, the most economical waste treatment alternative.

5.2 Instruments for change: From throughput to roundput

"What if" scenarios for throughput and roundput flows of waste management will present the potential alternatives of where do we want to go? As presented above, it was possible to numerate roundput flows and technologies were possible to quantity by using calculation models to describe throughput and roundput, especially with environmental and economic parameters.

However, in order to change the throughput flow model to the industrial ecosystem roundput vision, there is a need to identify some critical management instruments and policies for sustainable development toward roundput type activities and technologies. This task has not been the particular aim of the thesis, and we can only present some brief remarks here.

5.2.1 An anchor tenant of an industrial ecosystem

To achieve practical implementation of the industrial ecosystem vision, roundput between industrial actors requires a special "driver" of the system (Burström & Korhonen 2001, Korhonen & Snäkin 2001). This is because regional or even local industrial ecology is unlikely to happen if there does not exist a certain support system to drive the co-operation effort in the system. In environmental management literature, several units as key players or drivers have been suggested in inter organisational management. For example "symbiosis institute" (Baas 1999), "process unit" (Wallner 1999), "separate co-ordinating unit" (Linnanen 1998) or "initiator/stimulator" (Brand and de Bruijn 1999) have been suggested as the industrial ecosystem driver of the certain region or industrial estate. In the thesis the possible driver of the system is defined as "an anchor tenant" (Ayres & Ayres 1996; Lowe 1997; Chertow 1998; Korhonen et al. 1999; Korhonen 2000; Korhonen 2001a; Korhonen & Snäkin 2001; Korhonen 2002a). An anchor tenant could be a "physical" or "institutional" anchor tenant (Burström & Korhonen 2001c; Korhonen 2000) aiming to drive regional environmental management toward the features of roundput or the vision of an industrial ecosystem. Here, the physical anchor tenant is discussed.

5.2.2 Physical anchor tenant

The physical anchor tenant is a local or regional actor, which is an influential driver of the main physical material and energy flows of the certain region (Burstrom & Korhonen 2001). For instance, a regional power plant with CHP could serve as the role of an anchor tenant. In CHP plants, waste materials and also renewable fuel materials (biomass from agriculture and food industry, and forestry), as well as fossil fuel materials (e.g. peat, coal, oil) can be used as input fuels in energy production. However, the input energy source in a more sustainable industrial ecosystem should be renewable based. The output of CHP, the energy, could become a cascading energy system including residential and commercial buildings as well as industry with electricity, processed steam and heat. In such a situation, with the CHP power plant the network of waste utilisation could emerge. This, of course, is a highly idealised vision.

5.2.3 Physical anchor tenant of the thesis

In agriculture and food industry, the physical anchor tenant, i.e. CHP plant, can be either a) based on biomass, i.e. wood combustion or b) based on anaerobic digestion (AD) technology. In figure 10 a physical anchor tenant of food industry manufacturing is presented.

In Figure 10, to transform the throughput system to a roundput system, the food product life cycle waste flows are treated and managed in a treatment unit that serves as the food industry life cycle of organic waste, wastewater and wastewater treatment sludge treatment, energy and fertiliser production unit. Such units could be larger centralised (regional) units or decentralised (local) farm-scale or municipal units. The technique in such processes uses the anaerobic digestion (AD) technology for biowastes and wastewater treatment sludge as well as incineration for combustible wastes. The anaerobic digestion method produces renewable energy and organic fertilisers.

In other words, such a key activity uses wastes as fuel and produces industrial process steam, district heat and electricity in CHP (utilises waste energy). The outputs include fertiliser, because, in the treatment unit, the organic or biowaste flows are processed. Produced energy is used in the agrofood life cycle and organic fertilisers are used in agriculture. Therefore, it is suggested in this thesis that these units could serve the purpose of the anchor tenant or the key activity of the agricultural and food industry roundput industrial ecosystem. By creating a use for waste material, wastewater and waste energy (heat) the use of virgin resources and non-renewables is reduced and the amount of wastes and emissions are reduced.

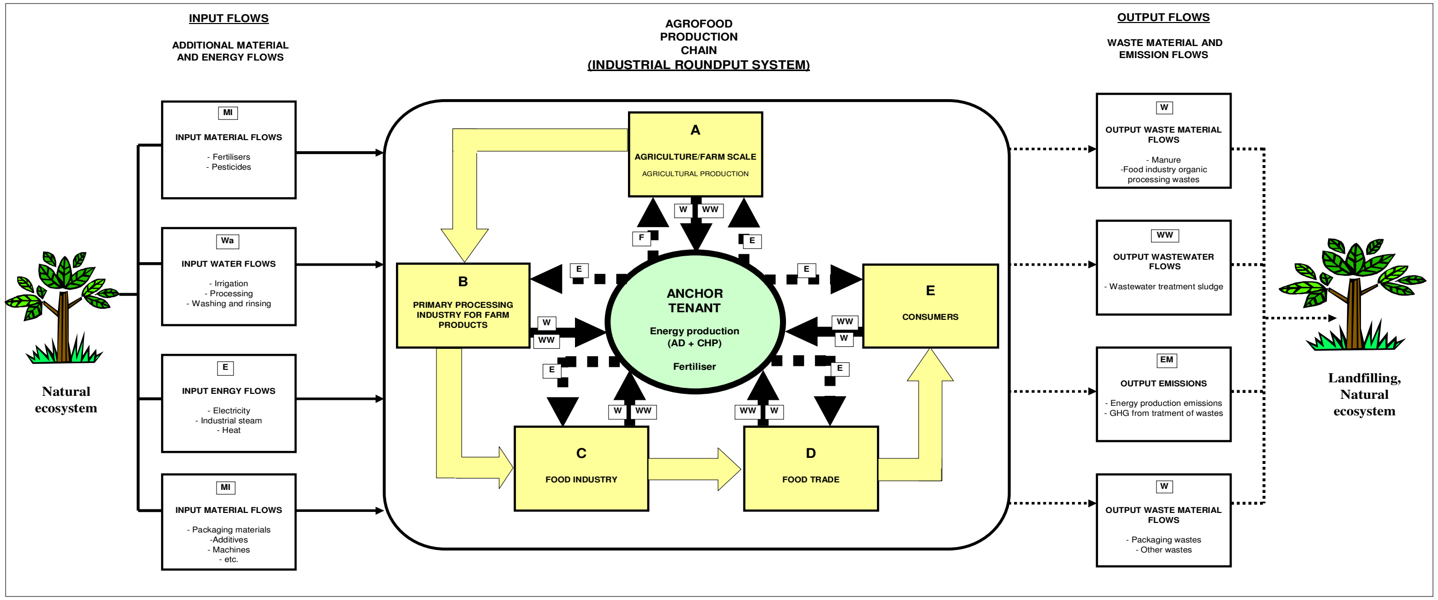

Figure 10. Agrofood roundput production chain with additional material and energy inputs as well as material and emission outputs. The system is arranged around an anchor activity, which uses wastes from the different life cycle steps as fuel and produces electricity as well as heat, which is derived from the waste energy of electricity production, for these different steps. In addition, the key activity generates fertilisers for the food product's life cycle. In this vision, the anchor tenant transforms the agricultural and food industry throughput into industrial ecosystem-type roundput.

This is to argue, that through diverse waste utilisation an industrial ecosystem type actor network could emerge. Nevertheless, note, as stated earlier, this thesis has only used methodologies and data on the physical flows of material and energy and some economic and employment data. The real change is always about people, the human side of industrial ecology (see e.g. Cohen-Rosenthal 2000). The work of this thesis should be further studied with methodologies and data from social sciences e.g., sociology, cultural, policy, management, organisational studies etc. This effort would require, for instance, an interview analysis of materials and surveys participative methods and observations, discourse analysis etc.

5.3 Barriers of change

Several barriers will most likely occur, when implementing the roundput vision in practise. This is also the case with plans to develop anaerobic digestion technology in the Finnish agriculture. First, the price of energy (electricity and heat) is relatively low in Finland. The average cost of electricity is about 0.076 EURO/kWh of produced electricity (Adato Energia Oy 2000). This means that the investments for AD technology have not been financially viable.

Second, the financial support for renewable energy production is not implemented in the full scale in Finland. If the renewable energy is produced in Finland, the producer will receive only the benefit of 0.0067 EURO/kWh of produced electricity. When comparing the situation to Germany, one finds that farmers are paid the minimum of 0.1 EURO per kWh of produced electricity (Holm-Nielsen & Al Seadi, 2000). This kind of policy would encourage farmers to invest in biogas production in Finland.

Third, in Finland, the dominant renewable energy production is based on biomass combustion, because of vast forest resources. Therefore, less "significant" opportunities or technologies are not receiving enough attention. In addition, the investment aids for biomass (i.e. wood based) combustion technology constitute the dominant factor in Finnish renewable energy policy. Perhaps, the decision-makers are not aware of the potential of biogas production in Finland, i.e. there has been an informational barrier in renewable energy potential calculations. Furthermore, anaerobic digestion has to be viewed from a larger perspective, not only for producing energy but also as an efficient waste management option for treatment of biowastes. The main barriers of AD as an anchor tenant are listed in table 11.

There are also some problems and barriers related to wood-based waste and residue utilisation in landfill construction, i.e. with the use of fiber clay or sludges, de-inking sludges and incineration ash. First, the relatively rigid legislation makes the development of soil construction industry as well as the utilisation of waste materials difficult in Finland. Wood residues are considered as waste materials. Because of this, the landfill construction process has to go through various processes before waste permission is granted. Second, the quality and environmental performance of the materials must be considered carefully. Waste residues have to be in line with some environmental characteristics, for instance, soluble concentrations of hazardous compounds have to be below certain limits dictated by authorities. Third, the price of virgin materials such as clay is cheap or equals the price of fiber clay. Nevertheless, note that the clay is becoming a scarce material in many parts in Finland and transportation distances are increasing, which shows in transportation costs as well as in the related energy consumption and emissions. Fourth, the attitudes towards wastes or side-products should change from repugnance against waste into behaviour that is more tolerant and towards the industrial ecology vision that waste could be seen as a valuable raw material and a resource with economic value.

Table 11. The main barriers of AD as an anchor tenant and waste utilisation for landfill management

Barriers of AD in biowaste treatment	**Explanation**
- Energy price - Financial support for technology by Goverment - Unfamiliarity of technology - Unfamiliarity of biogas potential in Finland - Other energy producing methods - Other waste treatment technologies	0,076 €/kWh of electricity does not exist only few AD reactors in Finland calculations are incomplete and not aware by desicion-makers wood based biomass is the main source of renewable energy for biowastes composting is seen "only" treatment option
Barriers of waste utilisation in landfill construction	**Explanation**
- Legislation - Environmental requirements - Price of virgin materials - Attitudes	byrocracy of waste permission process needs expensive and time consuming laboratory tests natural clay and sand are inexpensive bulk materials waste is seen as negative material

A Finnish research, development and presentation (marketing) project of fibre clay was started in 1997. During the two years of the project, the mechanical, hydraulic and environmental behaviour of wood-based sludges were tested and analysed in both field and laboratory tests. The result of the development process was a trademark, FINNCAO L8[11]. Based on the results, one could argue that the material is suitable and fulfills the quality and environmental requirements for soil construction industry (Niutanen 2000). However, some argue that the development process is not helping to change the waste permission process, because the results of the research have not been thoroughly acknowledged in policy and legislative decision-making. The main barriers of waste utilisation in landfill management are listed in table 11.

[11] Further information on testing the material and FINNCAO concept, see Pinnioja-Saarinen 2000.

6 CONCLUSION

This thesis attempted to study the applicability and the potential of the roundput system metaphor to certain regional industrial waste systems in terms of sustainable development.

The thesis used “what if” scenarios methodology to study throughput and roundput flows of presented models.

Decision-making requires a systematic and holistic approach to regional sustainable development management. The modelling by using “what if” scenarios of environmental, economical and social aspects with the presented method can help decision makers to steer the regional socio-economic development from unsustainable throughput flow model towards the principles of sustainable roundput flow model. These materials and energy flow concepts in agriculture and food industry serve to illustrate the emerging research and practical field of industrial ecology. Three case studies with three different model and scenario approaches were studied to answer the specific research question: what is the potential of the industrial ecosystem roudput material and energy flow model in regional waste management systems.

The scenario analysis yields three main results.

- First, the industrial ecosystem metaphor is beneficial in studying the physical flows of matter and energy. The metaphor can yield models with which a vision and a direction toward more sustainable material and energy flow models can be constructed.
- Second, the difference between ecosystems and economic systems is still so radical, that, at best, the ecosystem metaphor can be used as a source of inspiration for simulations and future scenarios and visions, not for giving practical management or design objectives and action-proposals for current day challenges.
- Third, the data and methodology used in this study cannot show evidence that the metaphor could be used to study the human dimension or the societal context of the material and energy flows. These results imply that the natural ecosystem metaphor, at this stage of development in literature, is best suited for engineering studies, material and energy flow systems analysis and inventory analysis and not for construction of practical management, organisatory or policy principles and programs.

I conclude that the potential of an ecosystem metaphor can be very useful as source of inspiration and creativity when conducting material and energy flow analysis and when building sustainability visions and future possibilities. Nevertheless, it must be noted, for using this thinking in practical analysis the metaphor has to be transformed and highly simplified, from qualitative models to quantitative criteria. In our analysis, the criteria were energy efficiency and emission intensity. The metaphor is very far from the current situation of the industrial economy linear and wasteful material and energy flows. It cannot be used as such for practical design, management or policy principles or action-proposals in policy programmes. It seems that it is very difficult to study the human side of the material and energy flow systems, the societal, institutional, policy, cultural, ethical or decision-making context of the flows with the metaphor. It appears that for practical implementation of the sustainability vision, one has to use other sources than the natural ecosystem metaphor, e.g. from social sciences, from cultural studies, or from management and organisational theories and methods. This kind of work in where natural ecosystem metaphor is used to enhance progress of industrial ecology toward more sustainable societies is a fruitful direction for future research and of course, from perspective of practical implementation of industrial ecology, extremely big challenge.

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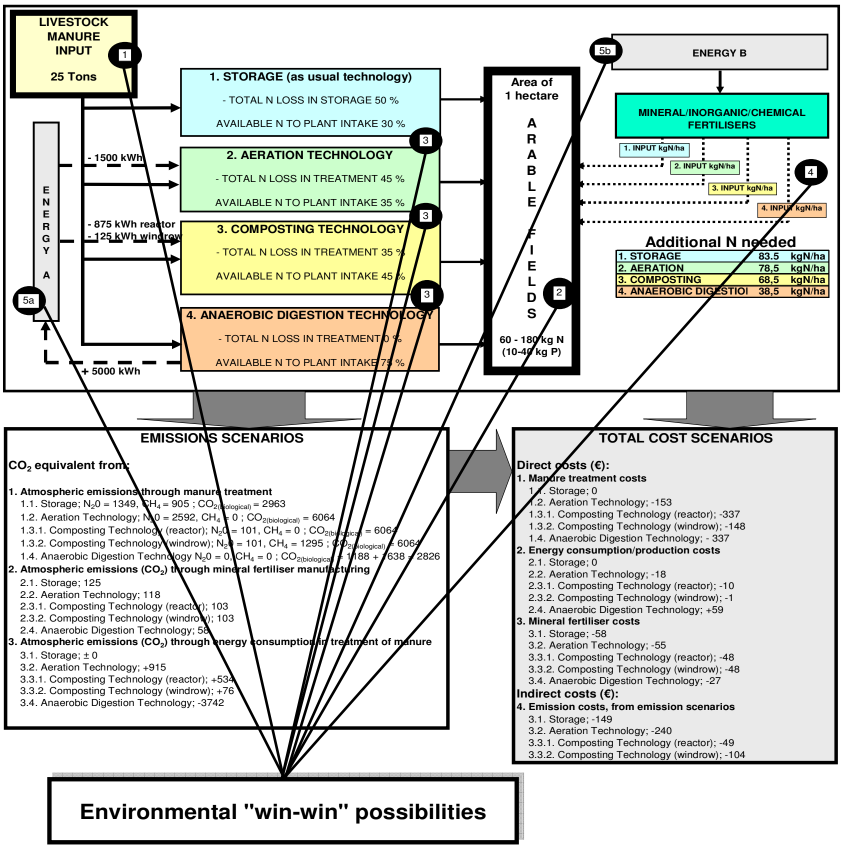
Appendix 1. Calculation methods, used data, assumptions and limitations of model I.

In the calculations in model I, the Excel (version 1997) spreadsheets were used. The “black circles” with number 1 – 5a and 5b describes the junctions where different calculation differences are available for present in agricultural manure management (see above figure). These are described as environmental “win-win” possibilities. First, the differences of manure management are determined and calculated, second, the emissions through different manure treatment technologies and issues depended on these treatment technologies are presented and finally, third, it is possible to present the total emission scenarios through total cost scenarios of different manure treatment technologies. By using this kind of approach throughput and roundput type manure treatment technologies can be presented.



Appendix 1, figure 1. Win-win possibilities of model I

Environmental Win 1 and 2

The first possibility to achieve environmentally beneficial solutions by changing the system is the use of the waste or side-product materials that is manure. To put it provocatively, the model I calls this the environmental win 1 as the manure waste is used maximally. The second potentially beneficial solution that is possible is the spreading of the gathered manure wastes onto arable fields (environmental win 2). In other words, wastes are used maximally and fertiliser inputs to fields are derived from these waste flows facilitating the reproduction of the agricultural ecosystem and helping to secure its nutrient balance.

In calculations, the system boundary of an arable field is defined as 1 hectare. European legislation, such as directives EU 1257/1999, EU 1750/1999, EU C/2000/1640, and in the national scale, "The commitment terms of environmental subsidies (2001)" determines the maximum input of the manure in terms of a one-hectare. Nitrogen (N) is allowed to amount between 60 - 180 kg/hectare and phosphorus (P) between 10 - 40 kg/hectare, depended on cultivated crops. For instance, in the cultivation of crops (i.e. wheat, rye), the N is allowed to amount to 90 kg/hectare and P to 15 kg/hectare. In average, the manure contains 3.4 kgN/ton of manure and 0.9 kgP/ton manure (Viljavuuspalvelu 2002). Therefore, in the above-described situation, the input of manure should be approximately / in average about 25 tons of manure per one hectare.

Environmental *Win 3*

The environmental win 3 describes the different manure treatment technologies and their possibility to maximise the fertilising values of livestock manure input onto arable fields. The technologies used in model I are divided into four different categories that serve as four different 'what if?' scenarios. The treatment technologies are storage of manure (1), aeration technology (2), composting technology (3) and anaerobic digestion (AD) technology (4).

Storage, aeration and composting are performed in an open environment, and therefore, some important nutrients are lost during the treatment of manure. These treatments (especially storage) are currently the most commonly used alternatives for the manure management in Finland. In these treatments, valuable nutrients are lost to air, instead of using the material maximally in agricultural fields. The treatments also alter the nitrogen into forms, which may be unavailable to plant intake. Usually, within storage, aeration and composting much of the nutrients in manure are locked up in their organic form (i.e. unusable nitrogen form for plants),

which furthermore reduces the availability for nutrients to plant uptake. Therefore, in the calculations, the main variables used are the total loss of nitrogen into air and available nitrogen to plant uptake %.
Anaerobic digestion (AD) is the only technology where the nutrient loss is neutral. Anaerobic digestion is a 'closed' treatment system and the nutrient losses are prevented (i.e. nutrient input = output value of manure). In addition, AD treatment keeps the treated manure in the most efficient nitrogen form, where plants are available to maximise their nitrogen uptake. In other words, the nutrients are recovered from the treatment and they can be used for their fertiliser value in fields. One can argue that the nutritional value of manure in anaerobic treatment constitutes the environmental win 3.

In the process of determining the nutrient losses and air emissions (i.e. greenhouse gases, GHG´s) in different treatment techniques and fertilisers % available for plant uptake in arable fields, the data used for modelling according to:

1. Storage (Kapuinen 1997; Hörnig et. al. 1999; Phillips et. al. 2000; Gronauer & Schattner 2002);
2. Aeration technology (Willers et. al. 1999; Béline et. al. 1999; Béline & Martinez 2002; Daumer et. al. 2001;)
3. Composting technology (Sonesson 1996; Sommer & Dahl 1999; Barton & Atwater 2002);
4. Anaerobic digestion technology (Aumônier 1997; Kübler & Rumphorst 1999; Klingler 2002; Dalemo et. al. 1998).

Environmental Win 4

The environmental win 4 is closely related to the treatment technologies in win 3. Hypothetically, the need for mineral fertiliser input is in direct ratio to nutrient losses in different manure treatment technologies. The win 4, then, arises through substituting the mineral fertilisers with manure-derived nutrients by using different treatment technologies and especially the efficiency of different treatment technologies.

The mineral fertiliser inputs onto arable fields are modelled by using the reference of storing, which is the most common agricultural practise in Finland. Then, the level is set of the quantity of plant nutrients sold in fertilisers of cultivated land by using the Yearbook of farm Statistics 2001 as a reference. Accordingly, the need of mineral fertiliser inputs after storage is 83.5 kgN/hectare. Other technologies are compared to this value, by reduction (- %) or by surplus (+ %). In determining the value of fertilising content of manure as well as mineral fertilisers, the market prices of fertilisers in Finland is used (Kemira Agro 2002).

Environmental Win 5

The environmental win 5 is divided into two categories a) and b). 5a describes the difference in energy required or production in different manure treatment technologies. Storing of manure is neutral in energy production/consumption. Aeration and composting require energy (energy negative, -), while anaerobic digestion produces energy (energy positive, +). When energy is produced instead of used, the use of natural energy sources is reduced and the emissions are reduced.

5b describes the energy required in mineral fertiliser production. The energy input is in direct ratio to mineral fertilisers needed in arable fields. The need of energy in the manufacturing process of mineral fertilisers is compared, first to the amount of 83.5 kg of nitrogen (i.e. the need of mineral fertiliser input after storing), and second, the energy need is converted to correspond the need of mineral fertilisers when using alternative manure treatment technologies, i.e. aeration, composting and AD.

Energy requirement and production rates are derived by using data of following references: (Aumônier 1997; Dalemo et. al. 1998; Kübler & Rumphorst 1999; Björklund et. al. 2000; Lehto & Ekholm 2001; Klingler 2002). When modelling the consumption of energy and its emissions in manufacturing mineral fertilisers we have used data of (UNEP 1998; Isherwood 2000; Febre Domene & Ayres 2001; Grönroos & Voutilainen 2001; UNEP 2001; Klinger 2002).

Summary of environmental win-win possibilities

The environmental results that can be achieved with different approaches in manure management are summarised and the overall emission scenarios are presented. Emissions occur in the following way:

1. Atmospheric emissions through manure treatment in different treatments (N_20, CH_4, CO_2)
2. Atmospheric emissions (CO_2) through mineral fertiliser manufacturing
3. Atmospheric emissions (CO_2) through energy consumption in treatment of manure (aeration and composting technology) and energy production (anaerobic digestion)

Atmospheric emissions are presented collectively as CO_2 – equivalents.

It is assumed that the energy needed in aeration and composting is produced with fossil fuel based fuels (oil) and without CHP. The energy produced in AD is assumed to be CHP.

Economic *Win*

The monetary value of the manure wastes is presented by using different treatment technologies. Costs are divided into two categories; direct costs and indirect costs. The total monetary value of manure is calculated and evaluated by using the following direct cost parameters: 1) Manure treatment costs with four different technologies, 2) energy costs (consumption in aeration and composting, production in AD) and 3) mineral fertiliser costs. The indirect monetary values (4) of the calculations are derived from the emission scenarios.

In the calculations,

- the definition of treatment costs and data is used by (Sonesson et. al. 2000; ICCP 2001a; Gronauer & Schattner 2002).
- Mineral fertiliser costs are adapted from statistics (Kemira Agro 2002, Yearbook of Farm Statistics 2001).
- In case of the monetary value of energy, we have used 11,76 EUR/MWh (Adato Energia Oy 2000).
- In case of the monetary value of CO_2 equivalent, the trading price of 81 US Dollars/CO_2 (≈ 65 €/CO_2) equivalent ton is used. This becomes meaningful, e.g. in a situation, in which a certain region can sell its emissions reduction ability to a region, which, in turn, has notably higher emissions.

Social Win

The social dimension, i.e. the employment opportunities are discussed and evaluated with different treatment technologies, as above, storage, aeration, composting and AD. In evaluating and describing the number of employment possibilities, the data of McNally (2001) is used. When preparing the employment scenarios the examination whether a greater investment in renewable energy technology (or technology itself) leads to more employment opportunities in Finland. To study, whether greater use of wastes and renewables as raw materials and as fuels creates positive effects in terms of employment, constitutes the social scenario.

Appendix 2. Calculation methods, used data, assumptions and limitations of model II

The general methods for calculations are adopted from previous waste management scenarios constructed in Sweden (Dalemo et al. 1997; Sonesson et al. 1997; Björklund et al. 1998) and in Finland (Tanskanen 2000; 1997; 1996). In the calculations, the Excel (version 1997) spreadsheets were used.

The calculations, used data, assumptions and limitations are based on the following steps in the waste management process:

- Quantity of different waste fractions in the case area
- Transportation and collection of waste fractions
- Treatment and disposal of waste

Quantity of different waste fractions in the case area

The data used in the calculations of the quantity of municipal solid waste, industrial waste, agricultural waste, wastewater treatment sludge and forestry waste flows have been adapted from following references:

- Insinööritoimisto Paavo Ristola Oy 2000
- Insinööritoimisto Paavo Ristola Oy 2000a
- Insinööritoimisto Paavo Ristola Oy 1996
- Järvenpää et. al. 1994
- Lehtimäki 1995
- Lehtimäki & Lundström 1994
- Lounais-Suomen Metsäkeskus 2001
- Nieminen & Isoaho 1994
- Satafood Kehittämisyhdistys ry 2000
- Suunnittelukeskus Oy 1999
- Tanskanen 2000; 1997; 1996
- http://statfin.stat.fi
- http://www.fennica.fi

The quantity of different waste fractions in case area is presented in table 6a.

Transportation and collection

Environmental and economic impacts of transportation are calculated by applying the waste collection and transportation model mainly by Nieminen and Isoaho (1994) that uses absolute and relative distances (i.e. time-distance) -based equations of waste collection and transportation activities. The model parameters are given in table below.

Appendix 2, table 1. Waste collection and transportation model by Isoaho and Nieminen 1994.

COLLECTION TIME AND TRANSPORTATION DISTANCES OF WASTES			
Symbol	**Parameter**	**Unit**	**Mathematical formula**
w	Amount of waste per one inhabitant	kg/inhabitant/a	
i	Amount of inhabitants	number	
W	Total amount of waste	kg/a	W=w*i
n	Number of collection sites	number	
e	Emptying frequency	number/a	constant 52
z	Amount of waste containers	number	Avg. 0,12 / inhabitant
ze	Amount of emptying	number/a	ze=z*e
tz	Time of emptying	min/unit	constant 0,6
Tz	Total time of emptying	min	Tz=ze*tz
tl	Preparation time in emptying	min/unit	constant 0,67
Tl	Total preparation time	min	Tl=tl*n*e
sr	Length of the collection route	km/route	estimated[1]
Sr	Total collection distance	km/a	Sr=sr*e
vr	Driving speed in the collection area	km/min	constant 0,33
Tr	Total driving time	min/a	Tr=Sr/vr
m	Maximum weight of the load	kg/load	constant 6000
K	Amount of loads	number/a	K=W/m
st	Distance to the emptying site	km	estimated[2]
vt	Driving spped outside the collection area	km/min	constant 0,83
Tt	Driving time (back and forth) to the emptying site	min/a	Tt=st/vt*K*2
tp	Time of unloading	min/load	constant 8
Tp	Total unloading time	min/a	Tp=tp*K
sv	Distance to the depot (from collection area)	km	Avg. 2,5
Tv	Total driving time to the depot area (back and forth)	min/a	Tv=D*2*sv/vt
D	Amount of working days	d/a	D=(h*(Tz+Tl+Tr+Tt+Tp))/(2*((30*td)-(h*(sv/vt))))
h	Waste-time factor		constant 1,15 (includes pauses)
T	Collection time in one year	h/a	T=(h*(Tz+Tl+Tr+Tt+Tp+Tv))/60
Tk	Collection time per one load	h/load	Tk=T/K
Tw	Collection time per one ton of waste	h/t	Tw=T/(W/1000)
td	Lenght of working day	h/d	constant 12
sh	Pause kilometres	km/d	constant 6
Sh	Pause kilometers per one year	km/a	Sh=sh/D
Sv	Total driving kilometres to the depot and back	km/a	Sv=sv*D*2
St	Driving kilometres to the emptying	km/a	St=st*K*2
Stot.	Total transportation distance	km/a	Stot.=St+Sr+Sh+Sv

COSTS			
Symbol	Parameter	Unit	
T	Total collection time	h/a	
wa	Wage	Euro/h	constant 20,17
Lc	Labour costs (wages)	Euro/a	Lc=T*wa
Id	Indirect labour costs (65%)	Euro/a	constant 0,65 (65%)
Ht	Total labour costs	Euro/a	Ht=Lc+Id
p	Fuel consumption	l/h	constant 8
hp	Fuel price per one liter	Euro/l	1 €
Hp	Total fuel costs	Euro/a	Hp=hp*p*T

[1] Lenghts of the collection routes were estimated by using values of 12 municipalities in the region by relating the value into land area of each municipality. Tl values of these 12 municipalities varied between 0,045-0,095 km/Sq^2. An average of 0,07 km/Sq2 was applied in calculations.

[2] Distance to the emptying site is based on the average distances between the municipal centres and regional waste management centres (The Finnish Roa Administartion, 2003).

Some parameters, e.g. the energy consumption of the transportation and collection vehicles are adapted from Swedish case studies or models (Durling & Jacobsson 2000, Sonesson 1996). In addition, transportation outside the collection routes (i.e. agricultural biowaste and wastewater treatment sludge) is calculated by using average distances between municipal centres and by applying the equations from the transportation model[12]. The calculations are based on the existing waste management structures, that are waste management and energy production infrastructure and institutional structures in the case region of Satakunta case area (waste management companies and municipal cooperation).

The waste transportation and collection model by Nieminen and Isoaho (1994) includes economic aspects for the collection and transportation times can be converted into personnel working years, and therefore, the labour costs of waste collection and transportation are able to calculate/determine. The labour unit costs are determined as an average (€/h) from the personal communication with regional waste management company (Haavisto 2001) and adaptation from Isoaho 1997. The economic parameter of the transportation is a combination of both fuel and labour costs that depend on the collection and transportation logistics. In addition, the transportation model by Nieminen and Isoaho is now applied further by aggregating average transportation emissions of different types of vehicles (available in LIPASTO- transportation model[13]) into the model.

Treatment and disposal

The waste treatment (i.e. processing) emissions for waste management consist of GHG emissions during the treatment processes. Emissions for composting, anaerobic digestion and incineration technologies are based on fuel emission factors, generally presented in Vehkalahti & Hämekoski (2001) and global warming potentials (IPCC, 2001). Technologies are assumed well functioning and representing the best available solutions.

Energy content in biowaste through AD is calculated by using below formula:

$$\mathrm{Ep} = \frac{Mj * VS * OM * T}{100}$$

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[12] Average transportation distances for agricultural biowaste and wastewater treatment sludge are based on the geographical information systems (GIS) –based measurements and average distances between the municipal centres (Finnish Road Administration, 2003. URL:<http://www.tiehallinto.fi>.)

[13] LIPASTO- transportation model is a calculation system for traffic exhaust emissions and energy consumption. (Technical Research Centre of Finland. <http://lipasto.vtt.fi>.)

Where,

Ep = energy potential
Mj= waste mass, kg, ton
TS[14]= Total solids of waste mass, %
VS = Organic content of TS [15], %
OM = Methane production capacity of TS in anaerobic treatment[16] m^3 CH_4/kg $VS_{added,}$ %
T = caloric heating value of methane (CH_4)[17] MJ, kWh

Emissions factors (i.e. TS, VS, OM and T) of anaerobic treatment of biowastes are adapted from following references Björklund 2000, Danish Institute of Agricultural and Fisheries Economics 1999, Eco technology JVV Oy 1995, Fortum Power and Heat Oy 2000, Holm-Nielsen & Al Seadi 2000, Kalmari et. al. 2001, Lehtimäki 1995, Lehtimäki & Lundström 1994, Suunnittelukeskus Oy 1999.

Energy content/consumption in biowaste through composting is calculated by using reference of (Björklund 2000).

- Reactor composting uses 35 kWh electricity per treated ton of biowaste while,
- Windrow composting (open air) uses 5 kWh electricity per treated ton of biowaste

Energy content in energy waste fractions through incineration:

- 1.3 MWh/m^3 of wood residual and energy crop (Ympäristöministeriö 2001, Korhonen 2000, Pipatti et. al. 1996, Järvenpää et. al. 1994)
- 4,8 MWh/ton of packaging waste (Ympäristöministeriö 2001, Korhonen 2000, Pipatti et. al. 1996, Järvenpää et. al. 1994)

The disposal-originated emissions are excluded from the case study mainly, because the functional unit of one year (2000) has been used in all

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[14] Municipal biowaste TS = 30 %; industrial biowaste TS = 17 %; waste water treatment sludge ; agriculture (manure) TS = 10 %
[15] VS ,75 %
[16] Municipal biowaste 0,55; industrial biowaste 0,2; waste water treatment sludge 0,43; manure 0,35
[17] CH_4 caloric heating value = 38,1 MJ/m^3 = 10,58 kWh/m^3

calculations and data concerning the history of regional waste management is not available for instance to implement the first order decay (FOD) – method[18]. Furthermore, it was assumed, that the regional landfills would be closed within 5 – 10 years, and therefore not simulating the situation in the future.

The economic costs and revenues for treatment and disposal are derived by using average unit running costs for different technologies (Pipatti et al., 1996; Savolainen et al., 2001, Eunomia, 2001). Unit running costs include the costs, e.g., from labour, electricity, water, wastewater treatment, chemicals, additives and machine work. Note that the investment costs are not included into the calculations, because they would decrease the comparability of the waste management alternatives by determining major part of the economic indicators and hiding the spatial and process-based differences. Nevertheless, it is evident that a large mass-burn incineration facility or AD-facilities would require new investments while landfilling, open composting and co-incineration have already an existing infrastructure in the Satakunta case region. In Finland compost or AD-residues have neither markets nor market value at the moment, which partly prevents the actualization of positive indirect impacts. Here, the recovered energy is assumed to replace fossil fuel–based energy (natural gas and oil), This is an indirect positive impact through reduced GHG-emissions and energy production costs (Eunomia, 2001) outside the waste management system, i.e., in the societal or economic sectors of agriculture, industry or residential household systems.

[18] First Order Decay (FOD) –method produces a time-dependent emission profile that reflects the pattern of waste degradation (IPCC, 2001b).

Appendix 3. Calculation methods, used data, assumptions and limitations of model III

In the environmental (i.e. energy balance and related emission parameters) calculations, the life cycle assessment program, KCL-ECO was used.

Data sources of the calculations

- Transport by road (sand 10 km, fiber and natural clay 50 km, geomembrane 120 km)
  - VTT Liisa program 1998.

- Transport by sea (bentonite transport from Wyoming USA to Finland 15 000 km)
  - MAN B & W Diesel 1997.

- Manufacturing of geomembrane;
  - Boustead 1999

- Digging, loading, spreading and compressing the material on landfill;
  - Puranen 1992